United States
Department of
Agriculture

Agricultural
Research Service

Miscellaneous
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Number 1429

# Agricultural Research Service Program Plan

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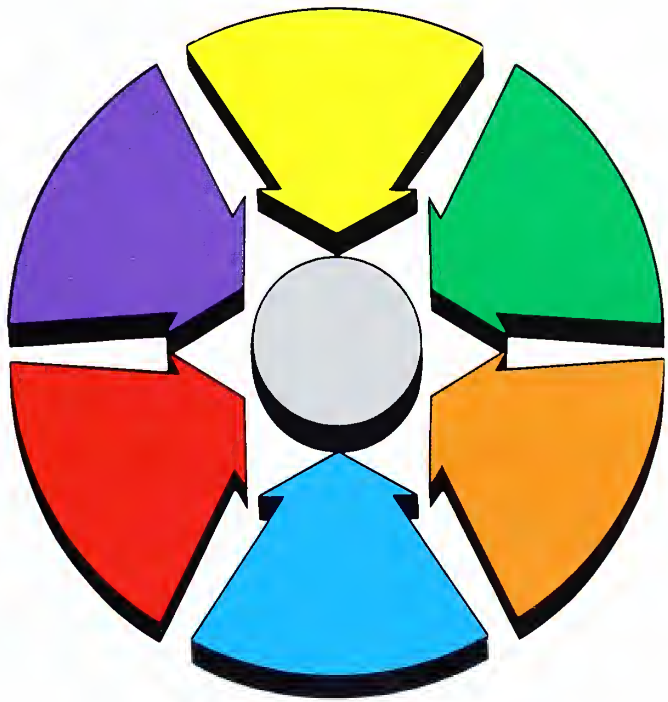

**Goal:**

Through fundamental and applied research, ARS seeks to provide the means for solving the technical food and agricultural problems of broad scope and high national priority as required to ensure, perpetually, an adequate supply of high-quality food and fiber for the American people and for export.

**Objectives:**

Develop the means for—

1. Managing and conserving the Nation's soil and water resources for a stable and productive agriculture;
2. Maintaining and increasing the productivity and quality of crop plants;
3. Increasing the productivity of animals and the quality of animal products;
4. Achieving maximum use of agricultural products for domestic markets and export;
5. Promoting optimum human health and well-being through improved nutrition and family resource management; and
6. Integrating scientific knowledge of agricultural production, processing, and marketing into systems that optimize resource management and facilitate transfer of technology to users.

## Foreword

The Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA) must respond to the needs of our complex agricultural enterprise. Agriculture accounts for about 20 percent of the Nation's business volume and employment and, in 1981, accounted for about 19 percent of its exports, but it does not always provide farmers with a reasonable return from their investments of land, labor, and capital. Our agricultural enterprise is committed to supplying the needs of consumers, at home and abroad, with wholesome, nutritious food and other farm products at affordable prices. In continuing to meet that commitment, U.S. agriculture faces an array of major challenges, which include conserving our natural resources, improving the efficiency of production, and increasing the use of farm products.

I asked ARS scientists and the National Program Staff (NPS) to devise a strategy that would provide, through research, the means by which U.S. agriculture could meet those challenges. In response, they developed this document, the ARS Program Plan. The Plan records the best thinking, of approximately 500 ARS scientists and the members of the NPS, on how ARS can meet agriculture's short- and long-term needs most effectively and efficiently. As my part in strategic planning, I revised the management philosophy of ARS and formulated the policies for the Implementation Strategy. The policies establish the principles and standards that will guide the Agency in following the Program Plan. They also provide guidelines for collaboration and teamwork among ARS employees in line and staff positions. In accordance with those policies, I will operate the ARS as a managed activity, coordinated by plan.

The Program Plan provides for close coordination with other research organizations in and out of USDA, the action agencies in USDA, and other organizations that use our research findings. I want to emphasize the special working relationships between ARS and the State Agricultural Experiment Stations. Cooperative research programs must continue their valuable contributions to the development of science for agriculture.

The Program Plan includes programs for meeting future, as well as present, needs of U.S. agriculture. On the basis of recommendations by the scientists and the NPS, and guided by the policies, a Six-Year Implementation Plan is being prepared. In it we identify the programs of highest priority that ARS will support first. We are developing the projected resource allocations for those high-priority research programs. That information will guide decisionmaking by management at all levels in ARS. Programs will be evaluated systematically to identify areas of significant progress, major constraints to further progress, emerging research problems and opportunities, and research that can be discontinued. Such evaluations will guide me in managing the physical, financial, and human resources of ARS.

We will measure the success of our strategic planning by our progress in the ARS mission of producing new knowledge and technologies for the Nation's food and agricultural enterprise. Evidence of our progress will be outstanding, innovative research that meets the needs of U.S. agriculture and that, in turn, will help sustain and improve the well-being of our people for generations to come.

T. B. Kinney

**T. B. Kinney, Jr.**
Administrator

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Issued January 1983

# The Agricultural Research Service Program Plan

## Summary

The Agricultural Research Service Program Plan represents the best thinking of about 500 scientists and members of the National Program Staff (NPS), Agricultural Research Service (ARS), U.S. Department of Agriculture (USDA), who participated in the strategic planning process. The Plan reflects the concern of the scientists about supplies of high-quality food and other farm products at affordable prices for U.S. citizens and for export, about the economic welfare of the U.S. agricultural enterprise, and about conserving the Nation's natural resources. Members of the NPS organized the ideas and recommendations of scientists into this Program Plan.

The goal of the Plan is to ensure, perpetually, an adequate supply of high-quality food and fiber for the American people and for export. The six objectives that will lead to the ARS goal deal with conserving and managing natural resources, increasing the productivity of plant crops and of livestock, marketing farm products efficiently, improving the nutrition of people, and developing agricultural systems. Each objective is presented in one of the six main sections of the Program Strategy. In each section, background information, needs that justify the research proposed, and the potential benefits of the research are reported. Research approaches and specific elements for each approach are listed and discussed. In the sections for the objectives, ARS scientists propose using the most advanced physical, chemical, and biological technologies to meet the short- and long-term needs of U.S. agriculture and, ultimately, to meet the needs of people worldwide. Those proposals provide a wealth of ideas for sparking new ARS programs well into the next century.

For the ARS Implementation Strategy of strategic planning, the Administrator established the six major policies that define his courses of action for operating ARS as a federally funded and managed agency. He will operate ARS as a managed activity coordinated by plan. The Deputy Administrator and the NPS are responsible for and are now developing the Six-Year Implementation Plan. The policies provide for the major functions needed for achieving the six objectives of the Program Strategy, and they assign the responsibility for establishing priorities in the Six-Year Implementation Plan. Regional administrators are responsible for operational plans, and the Administrator has overall responsibility for coordination and execution of the programs. The Deputy Administrator is responsible for systematic evaluation of programs. The ARS is continuing its research in, and its exchange of technology with, foreign countries. The policies were designed to ensure that ARS, the primary research agency of USDA, functions effectively and efficiently.

By policy, the ARS Program Plan provides an optimum balance between the fundamental research needed for long-term solutions to agricultural problems and the applied research needed by action agencies in the Department and by other users of research to carry out their responsibilities. The Plan stresses the innovation and creativity that characterize the ARS research program. By their strategic planning, ARS scientists ensure that their Agency can mobilize its talent and facilities to develop the science needed to meet present and future challenges to U.S. agriculture.

## Introduction

Research has revolutionized American agriculture. No aspect has gone untouched, from the planting of superior seeds to the ultimate consumption of wholesome and nutritious food. Farmers and agribusinesses apply research findings in the use of natural resources and produce an abundance of food and fiber unmatched in the history of mankind. Agricultural productivity, which has increased a phenomenal 240 percent in the past 50 years, has freed millions of people for other kinds of work and accounted for much of the industrial growth in the United States. Today, about 22 million people work in some phase of agricultural production, processing, and distribution and make agriculture and its related industries our largest business. Americans spend a smaller proportion of their income on food—about 16 percent—than do people in any other country.

### Challenges to Agriculture

Despite the past performance record of American agriculture and the current surpluses of some crops, many studies and assessments question its ability to meet future demands for food and other agricultural products. The main challenges are as follows:

• The United States has become the residual supplier of agricultural commodities for a growing world population. In 1981, crops harvested from nearly 40 percent of all U.S. acreage and valued at about $44 billion were destined for foreign markets. World food production must double in the next 40 years to meet projected demands.

• Our base of natural resources has declined in quantity and quality because ground-water supplies have diminished, farmlands and irrigation water have been lost to other uses, and excessive erosion of top soil continues from about a third of our farmlands. Additional land and water supplies can be developed, but their costs will be higher and their productivity lower than for those now in use.

• The productivity of key components of agriculture is beginning to peak or flatten out. Average farm yields of crops such as cotton, rice, sugarcane, and dry edible beans have not increased in many years, and yields of other crops may also be peaking. The productivity of farmers' inputs actually declined 7 percent during the 1970's. That trend is continuing into the 1980's; farmers' costs for inputs are increasing and the productivity of the inputs is generally decreasing.

• We face an increasing number of new constraints that include high costs of petroleum and natural gas and of products, such as fertilizer, that are derived from them; increasingly erratic weather patterns in the past decade; only fair to poor condition of about 60 percent of our rangelands; increasing regulation of agricultural chemicals and processes; and many actual or potential environmental constraints, such as air pollution and declining water quality.

• Improving the economic health of agriculture and of its independent entrepreneurs is a major challenge. To adopt new technologies and to meet the anticipated needs of future generations, agricultural business must be economically strong.

All the energy that is essential for the growth of plants—and, therefore, for the production of food and fiber—comes from the sun. Green plant tissues capture the sun's energy in chlorophyll and, by photosynthesis, make the chemical compounds that we eventually use for food, clothing, shelter, and other purposes. However, plants capture only a small fraction of the sunlight available on earth. Animals convert plant materials into meat, milk, and other foods. However, humans eat, as primary foods, only a small fraction of the plant materials produced; most plants are grown as food for animals. To meet projected needs of the world's growing population and to enhance its standard of living, scientists must optimize photosynthesis by plants and the conversion of plants to animal products.

Because the land area suitable for growing crops is limited, food and fiber production with existing technologies and management practices will also be limited. Are we approaching that limit? Some experts argue that we may already have exceeded the long-term, sustainable productive capacity of the earth. Others argue that we have barely scratched the surface of productive capacity.

Scientists who question the sustainability of current agricultural capacity point out its heavy dependence on energy from fossil fuels that store the energy captured through photosynthesis by green plants that lived millions of years ago. Our food production, therefore, depends not only upon the energy available from the sun daily, but also upon prehistoric sunlight stored in fossil fuels. As we deplete those nonrenewable energy reserves, the potential for agricultural production from them will be lost or become increasingly more expensive.

About half the original topsoil has been removed from U.S. farmlands by erosion. About one-third of the ground water used for irrigation in the 17 Western States is being pumped from aquifers faster than they can be recharged. Other causes for concern include loss of farmlands and irrigation water to other uses, depletion of phosphate

reserves, salinization of land and water, loss of potentially valuable germplasm, and adverse effects of pollutants such as acid rain.

The yields of some crops are not increasing. Most of the people in the world eat rice and wear cotton clothes. Despite high inputs of fossil fuels and technology, neither rice nor cotton yields have increased appreciably in the United States since 1965. Their rates of yield increase are stalled (fig. 1). Although future demands for cotton products and rice are not clear, most estimates indicate that demands will increase. How then will the yields and production efficiency of cotton and rice be increased?

Scientists and others who argue that we have much unused productive capacity make several claims. They point out that the primary goal of past research was to increase production per unit of land and of labor, the two most costly production factors. Thus, they argue, the past record may not be a valid basis for accurately predicting the ability of scientists to improve the yields of crops and the efficiency of resource use in the future. Those people claim that because farmers' average crop yields are only a third or less of maximum experimental crop yields, considerable biological potential remains to be exploited. They also claim that, so far, we have always found ways to increase productivity. A novel claim is that the complex of modern technologies provides a new resource—technology itself—that generates "science power." Unlike natural resources, technology is manmade and its proponents think that science power could increase agricultural productivity indefinitely, as depicted for the last 50 years in figure 2.

The concept of science power piques our imaginations and heightens our expectations. For example, dare we expect that, when conventional techniques have failed, scientists could use science power to produce plants that capture extra sunlight or to produce cereal crops that fix nitrogen directly from the air? Dare we expect that they will use science power to slow the drain on our natural resources or to harness new sources of energy as substitutes for fossil fuels? We can imagine that those feats—and others—are possible. If we expect to realize such feats, however, we must gain the fundamental knowledge and experience necessary to address the constraints that limit agricultural productivity today. We cannot predict accurately the shape that the productivity growth curve will assume by the year 2000. Nor can we predict that science power will continue indefinitely to support growth at the rate indicated by extrapolation of figure 2.

Of the growth in overall productivity attributed to science power, how much accrued from innovation, without extra drain on our natural resources? The use of improved crop varieties does increase yield, but often the increase is at least partially due to their use of extra nitrogen fertilizer. Examples are the short, stiff-straw rice and wheat cultivars that resist lodging even when highly fertilized. The data indicate that those and other high-yielding crops do not use fertilizer more efficiently than do other crops, they just use more of it. Some crop breeders think that we have largely exploited the advantages of the short, stiff-straw characteristic in those crops. Many authors report that past increases in production depend, in fact, upon increased use of fossil fuels, water, chemicals of many kinds, and other resources.

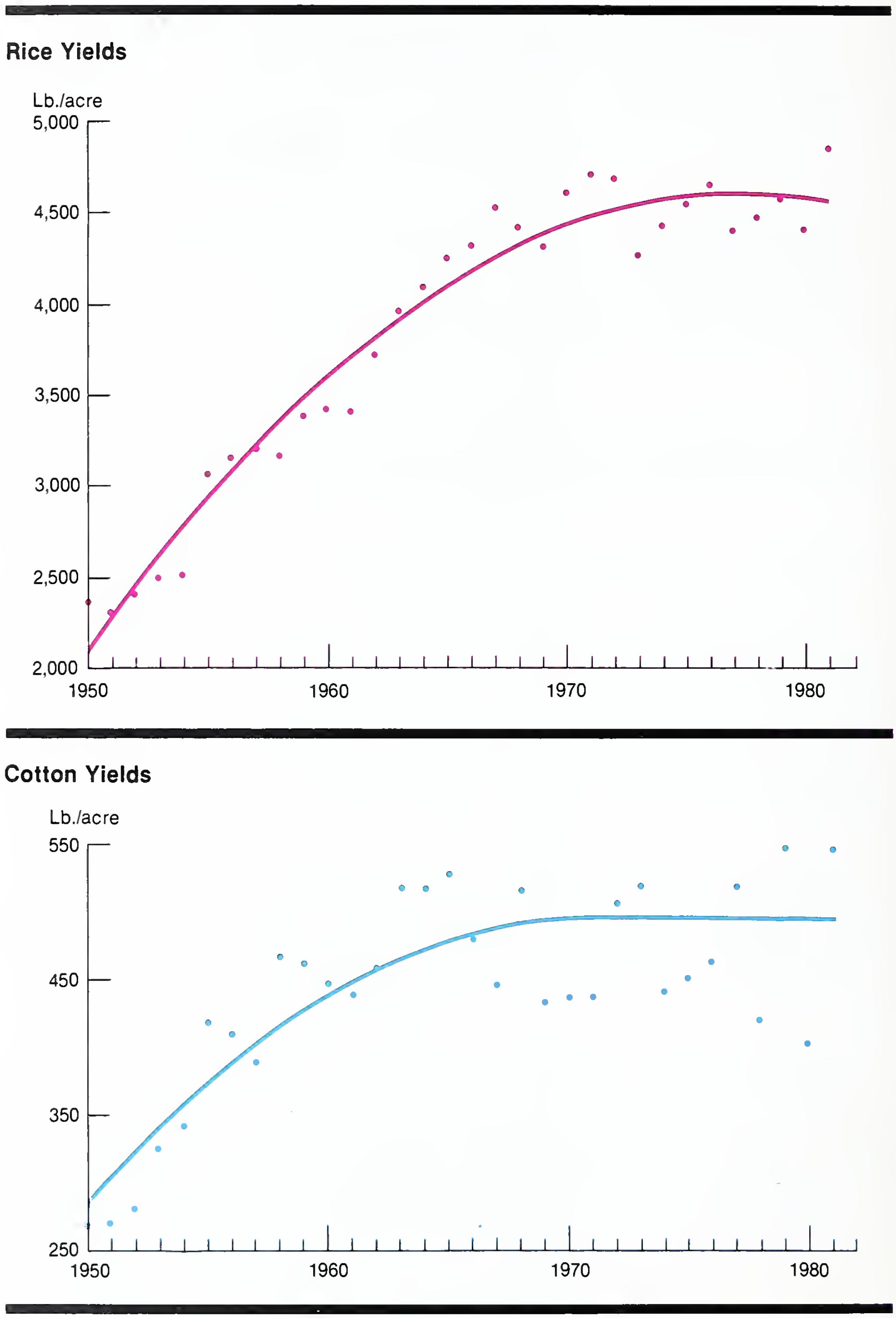



FIGURE 1.—Yield trends for rice and cotton (from Needs Assessment Committee Report, "Future Needs for Agricultural Products and Resources," 1981).

Related to the question of sustaining long-term growth in productivity is the need for year-to-year stability. Because so little food is stored worldwide each year, and because the differences between shortages and surpluses often are less than 10 percent of average production, our ability to feed ourselves and to export food and feed crops is determined to a considerable extent by production in the worst years, rather than by that in average years. Production stability is related more closely to weather than to any other factor, and the erratic weather patterns of the past decade probably are more typical of the norm than are the stable patterns of the 1950's and 1960's. As the world population grows and production potentials are reached, we may not have the crop surpluses of the past to tide us over severe droughts like the one in 1980.

Prediction of the effects of the main challenges to agriculture on supplies and costs of food and feed would be speculative. Most experts seem to agree that the demand for export of large quantities of grains and other farm products will continue. However, our land reserves will be used fully in the next 20 to 30 years, and any further increases in supplies of food, feed, and fiber must come from increased productivity of our natural resources, our crops and livestock, and our marketing systems. Even with low-demand projections, the required rates of productivity translate into dramatic numbers—275 bushels per acre of corn by the year 2000 and 385 bushels per acre by the year 2050. Such yields equal or exceed the highest experimental yields ever produced and are about three times as high as average farm yields (110 bushels of corn per acre in 1981). With

**U.S. Agricultural Productivity Growth During the Past 200 Years**

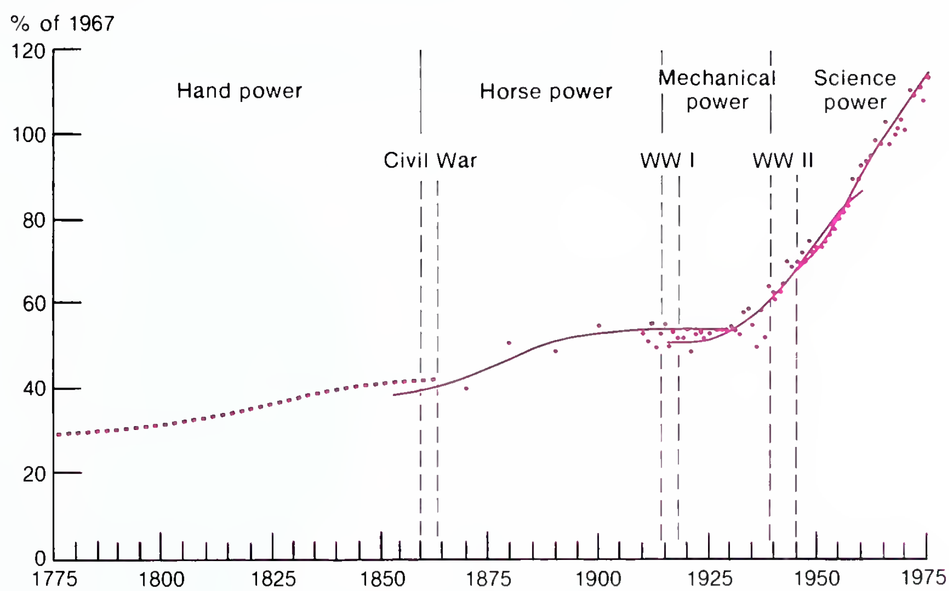



FIGURE 2.—Growth of U.S. agricultural productivity during the past 200 years. (Lu, Yau-Chi, Philip Cline, and Leroy Quance. Prospects for Productivity Growth in U.S. Agriculture. USDA Agricultural Economic Report No. 435, Sept. 1979.)

high-demand projections, the yields required would be higher than the limits imposed by the photosynthetic capacity of today's crops. Production of crops and livestock is only part of the story. Raw agricultural products must be marketed and processed into useful forms. Only through radically improved technology can we develop the marketing systems needed for efficiently handling, storing, and processing such huge quantities of food and fiber.

The success or failure of science as a whole might well be judged by the success or failure of the agricultural sciences during the next few decades. Without adequate scientific knowledge, we have little hope of responding rationally to the risks and uncertainties of an unpredictable future.

## The Challenge to Agricultural Research

Many groups fund and perform research and development for agriculture. The major contributors and the percentage of funds from each are shown in figure 3. The private sector provides the major share of the funding, predominantly in the physical sciences and engineering, for developing processes and products that yield a profit in the marketplace. In contrast, public research funds are concentrated in biological sciences and technology, where profits are not so easily captured. Public funds also support a larger proportion of long-term and basic research than do funds provided by industry. Public funds, both State and Federal, are crucial for continued support of higher education in all phases of agriculture where research is an integral and essential part of advanced training in the biological, social, and physical sciences and in engineering. The "other Federal" category includes funds for agencies such as the Forest Service, Economic Research Service, and Cooperative State Research Service in the U.S. Department of Agriculture (USDA), as well as for many agencies outside the Department.

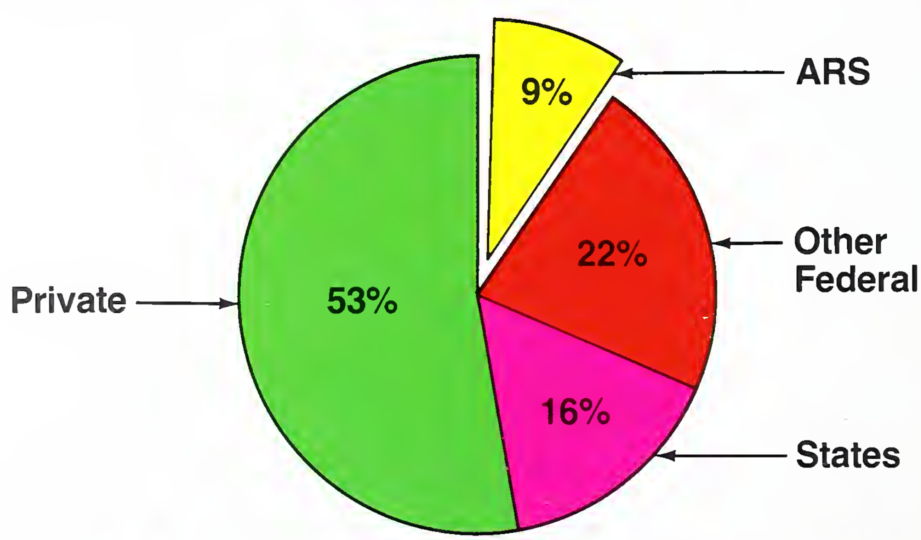



FIGURE 3.—Public and private funds for U.S. food and agricultural research.

The Agricultural Research Service (ARS) is the Department's principal intramural research agency. It has long-standing working relationships with the other research agencies in the Department, the State Agricultural Experiment Stations, and the private research sector. The ARS also works closely with the action agencies in the Department and serves as the research arm for many of them. Interagency programs within the Department are critical in such areas as soil and water conservation, range improvement, control of plant and animal diseases, and food safety.

The mission of the ARS is—

> To plan, develop, and implement research that is designed to produce the new knowledge and technologies required to assure the continuing vitality of the Nation's food and agricultural enterprise. As a Federal research agency, ARS (1) addresses problems that are of legitimate national concern, (2) conducts research that is appropriate for the Federal Government, and (3) exploits the unique capabilities of ARS scientists and the facilities they operate—a combination that forms an integrated and coordinated national resource that is not duplicated by others in the full U.S. agricultural research and development system.

In fulfilling its responsibility for assuring that the Nation has adequate supplies of high-quality food and fiber, the Department supports a wide range of research and educational activities, but it is primarily the ARS that must address the long-range, high-risk problems of national and international concern. The two overriding objectives of the Administration are bolstering national security and strengthening the national economy. No scientific effort is more critical to serving both objectives than is the mission-oriented research of ARS. A flagging agricultural technology—costly and erratic food supplies and depleted natural resources—is not in the national interest. Food is as critical to national security as are armaments. Agriculture, the Nation's largest industry, is in serious economic difficulty, and ways must be sought to restore its prosperity and to ensure its long-term stability.

The resources of ARS provide a sound foundation for developing the means by which agricultural technology may meet the enormous demands of future years. Those resources are as follows:

- *Critical mass of scientific capabilities,* comprised of more than 2,700 scientists and engineers, plus technical support staff, with the knowledge, technical expertise, and specialized scientific equipment to respond to broad regional and national problems.

- *Unique facilities and laboratories,* developed for all the disciplines demanded by agricultural research. Many are highly specialized laboratories; for example, those for the study of exotic diseases of plants and animals. Facilities are located strategically across the major farm and rangeland ecosystems and climatic zones of the United States. The world's largest multidisciplinary agricultural research center is at Beltsville, Md.

- *Organizational capability and central management to assemble resources,* including interdisciplinary teams to address broad geographic problems, the research needs of action agencies and other Federal organizations, and other high-priority needs for knowledge and technology. ARS has institutional arrangements for working with State Agricultural Experiment Stations, industrial research institutions, and others to bring outside talents and resources to bear on problem solving. The ARS also maintains international activities to mobilize the talents of foreign scientists and laboratories.

- *Unique germplasm collections and repositories of species of agricultural importance,* including world collections of most of the major crop plants and many potential new crops, clonal repositories, disease-free seed stocks, collections of microbes and insects, and unique herds and flocks of animals.

The ARS is challenged to manage its resources efficiently and effectively. In response to that challenge, it must assure the Nation that the Federal commitment to agricultural research is sufficient to deliver the science and technology that are essential to meet the continuing, long-term needs of national and world agriculture.

**The ARS Program Plan**

As illustrated in figure 4, the ARS Program Plan is the result of strategic and operational planning. This document describes the Program Strategy of strategic planning. It also introduces the Implementation Strategy by presenting the six major policies of the Agency. Based on the Program Strategy and those policies, a Six-Year Implementation Plan and resource projections are being prepared. They, in turn, will guide operational planning, resource allocation, and program execution for achieving the six objectives. Thus, this Program Plan will enable the ARS to mobilize its resources—talent and facilities—in a united effort to achieve its goal and to serve the U.S. agricultural enterprise.

As a Federal agency, ARS concentrates on research problems that are high-risk, long-range, and of national or regional scope. Such research requires unified planning, continuity of effort, a stable scientific environment, and the ability and flexibility to commit the necessary resources to high-priority needs that only a centrally funded, national organization can address. In accordance with its mission, the ARS also must continue to meet its responsibilities to support quarantine and other action programs, foreign policy initiatives, important national and international germplasm collections, and special emergency programs of regional or national significance. The need to integrate those responsibilities into the ARS program, with its disciplinary research in support of the six objectives, emphasizes the requirement for a planned and centrally managed operation.

Few people realize the technical and scientific complexity of the business of food and agriculture. The research programs of ARS must address that complexity in a logical and consistent manner. The success of the Nation's agriculture is influenced by an array of complex problems that can be physical or biological, and the scientific responsibilities of ARS must span the whole array for effective discharge of its assigned responsibilities.

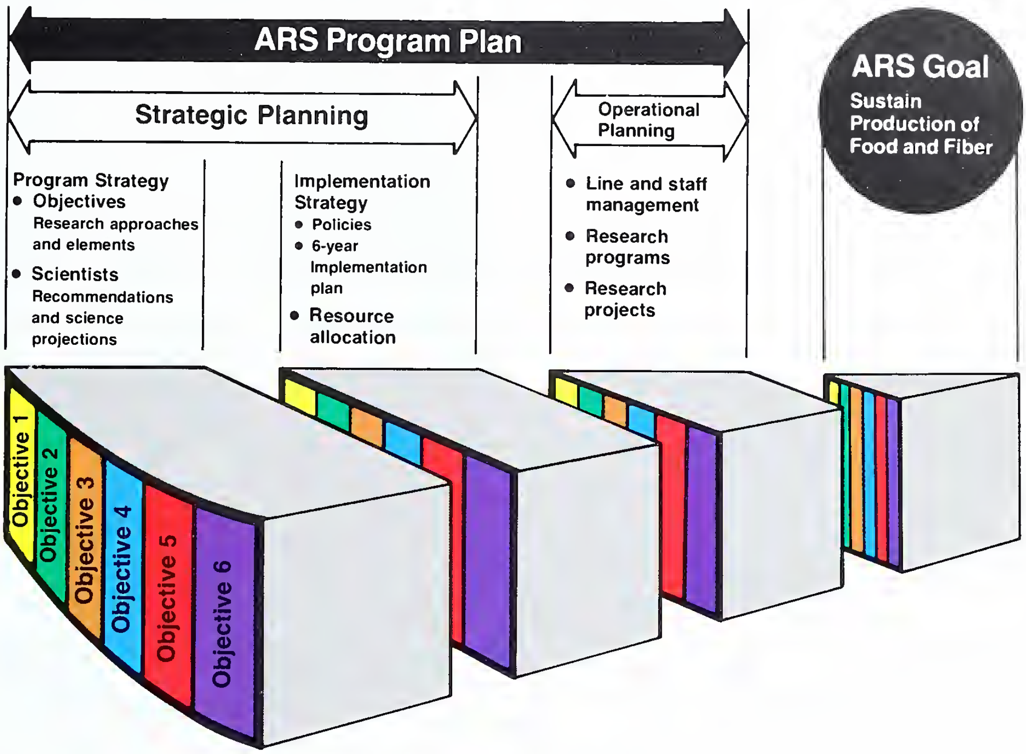



FIGURE 4.—The relationship of strategic and operational planning to the ARS goal and objectives.

As illustrated in figure 5, the Program Strategy of the ARS Program Plan was designed around a goal that is addressed by six objectives; progress on the objectives will result in progress toward the goal. With that design, all levels of organization, from individual laboratories to headquarters staffs and administrators, can use the Plan; all phases of research—ranging from studies of plant and animal genes to studies of bread and meat—can contribute to the goal.

Planning by ARS is an ongoing process, and through annual updating to reflect changes in priorities, appropriations, personnel shifts, and new research findings, the Plan will remain a dynamic document. The Six-Year Implementation Plan will be used by management as a baseline for evaluating progress and reallocating resources.

Line managers and members of the National Program Staff (NPS) developed the following goal and objectives for the Agency. They considered authorizing legislation, policy statements from the Secretary and the Assistant Secretary for Science and Education of the Department, and the common program structure developed by the Joint Council on Food and Agricultural Sciences.


FIGURE 5.—The ARS Program Strategy—goal and objectives.

**Goal:**
Through fundamental and applied research, ARS seeks to provide the means for solving the technical food and agricultural problems of broad scope and high national priority as required to ensure, perpetually, an adequate supply of high-quality food and fiber for the American people and for export.

**Objectives:**
Develop the means for—

1. Managing and conserving the Nation's soil and water resources for a stable and productive agriculture;

2. Maintaining and increasing the productivity and quality of crop plants;

3. Increasing the productivity of animals and the quality of animal products;

4. Achieving maximum use of agricultural products for domestic markets and export;

5. Promoting optimum human health and well-being through improved nutrition and family resource management; and

6. Integrating scientific knowledge of agricultural production, processing, and marketing into systems that optimize resource management and facilitate transfer of technology to users.

The six objectives describe the aims of ARS science. The words "develop the means for" are important. The ARS is a research agency; farmers and ranchers, action agencies, and the private section will actually achieve the stated objectives. The ARS is not the only agricultural research organization working on these or related objectives. The State Agricultural Experiment Stations and Land-Grant Universities contribute to them. Each State also has a Cooperative Extension Service office, Soil Conservation Service offices, and other organizations to help transfer research findings to users. Other Federal agencies, non-Land-Grant Universities, private foundations, and other institutions conduct research on problems that are important to food and agriculture. Industrial organizations conduct research on farming equipment, crops and livestock, agrichemicals, pharmaceuticals, product improvement, marketing, and nutrition—to name but a few. The ARS Program Plan will ensure that our research complements and supports, rather than duplicates, those other efforts.

All six objectives are essential, and achieving them wholly or in part will help meet the stated goal. Conservation and restoration can ensure that the resource base remains adequate for future generations. Increasing the productivity of our crop plants and livestock should help ensure farmers' margin of profit and provide food and fiber to consumers at reasonable costs. Producing food and fiber crops, however, is not enough; raw materials must be processed and delivered in an efficient and timely manner for ultimate consumption. Through all stages of production, marketing, and consumption, products must be protected against losses from diseases and from insects and other pests. Just as important are the safety, wholesomeness, and quality of the products, especially of the basic foodstuffs. Finally, total management systems must be developed to integrate and optimize the use of all basic resources and production factors to ensure that food and other agricultural necessities will be available.

This ARS Program Plan identifies and explains the main problems that confront the agricultural industry and charts the minimum courses of action that will provide the research needed for solutions to the problems. The current ARS budget of about $450 million annually has approximately the same purchasing power as did the 1966 budget. Clearly, the kinds of numbers of projects that can be undertaken within 1966 budget levels are limited. Hard choices must be made. Seventy percent of the members of the ARS scientific staff are 40 years of age or older. That figure implies that turnover and loss of specialists with experience will be extensive during the next few years. We also face a shortage of young, recently trained engineers, computer scientists, biophysicists, molecular biologists, and other critical specialists in the rapidly evolving disciplines needed to solve the problems of the future. To fulfill the Federal commitment of delivering the science and technology that are essential to meet continuing, long-term needs of agriculture, the ARS must maintain a research climate that attracts and retains the best scientists and creative thinkers.

In the past, especially during times of surpluses, various people have argued that production research should be stopped, or at least deemphasized. Conversely, during emergencies or times of shortages, researchers are asked to supply immediate solutions. Research cannot be turned on and off like a water faucet. Stability and long-term commitments are required. For example, research on Marek's disease of poultry caused by a tumor virus was initiated in 1939. The causative virus was not isolated until 1967, and a vaccine was licensed for national use in 1971. By 1974 the annual benefit from the vaccine was $180 million, at a total cost of $31 million in public research funds. Many examples of long lead times can be given for other kinds of technologies, as well as high rates of return from use of the technologies.

## The ARS Program Strategy

Agricultural science has been characterized as "the mother of sciences" in recognition of its early development and profound influence on both science and society. We have a vast knowledge base for managing resources, producing crops and livestock, and processing and transporting food and fiber. Some scientists and policymakers, however, question whether our agricultural industry can meet long-term national and export needs and whether ARS, as a research agency, can develop the new technology that would be essential for meeting those long-term needs. The design of the ARS Program Strategy provides for building most effectively on our present scientific knowledge base to identify and pursue the most promising research opportunities, thereby promoting the research that produces entirely new knowledge and technologies. We intend to balance the activities of our program across the spectrum of agricultural research; we will identify the most promising research opportunities, both basic and applied, by considering the supporting knowledge base, the probability of success, and the potential impact of success on our efforts to meet future national agricultural needs.

### Overall Research Strategies

Strategies for future production of food and fiber must identify the research that has the highest potential for achieving our objectives through alternative courses of action. The limits of productive capacity that are imposed by current technologies and finite natural resources are real, and they probably will become constraining as they are surpassed by demand. We must conserve our natural resources for future generations. The possibility of substantially increasing food supplies is based on the assumption that we can develop totally new technologies that might increase the efficiency with which plants use the sun's energy to convert soil nutrients, fertilizer, and water into food for humans. In some biotechnological approaches, plants would be replaced by another means of synthesizing food. We may need such revolutionary technologies if we are to reduce the amount of natural resources used in producing food and fiber. Equally important will be the development of improved technologies to augment existing systems for production of plants and animals. Development of revolutionary technologies will take time, and we should get started, but we must temper our optimism about revolutionary technologies. So far we have produced very few, and we must not risk diversion of all our effort from tested and proved research approaches. While we explore new technologies that might rescue us from our dependence on nonrenewable resources, we must intensify our efforts to maintain and improve the productive capability of our agricultural systems.

We need to help farmers and ranchers escape their current economic dilemma—net incomes that are comparable to those of the 1930's. Those independent entrepreneurs, the primary producers of food and fiber, must have an economic environment in which they realize sufficient return, and—thereby—incentive, to incorporate new methods and technologies into their production practices. Only farmers and ranchers who are financially strong can afford the risk of testing new methods in their operations. No national agricultural strategy will succeed unless farmers realize profit. The information produced by research can help not only to reduce production costs, but also to improve economic and political decisions related to agriculture.

Three broad strategies thus emerge for ensuring national security in terms of the quantity and quality of future food and fiber supplies. Those three strategies are represented at different points in each of the six objectives. They are—

- Develop knowledge of and technology for conserving and protecting our endowment of basic resources such as germplasm, soil, and water.

- Develop knowledge of and technology for exploiting known production potentials by closing the gap between average and record yields, reducing losses, and improving the efficiency of current production and marketing systems.

- Develop totally new technologies for producing, processing, and marketing the vast quantities of food, fiber, and other agricultural products that will be needed in the next century and beyond.

The Program Strategy is based on science. The ideas and recommendations of approximately 500 ARS scientists and members of the NPS are summarized in the objectives presented and discussed on the following pages. Research approaches and approach elements that outline the scientific efforts needed to achieve the ARS goal are presented in each objective. The approaches and elements define research strategies and do not necessarily represent current or planned operating programs. Individual programs are, and will continue to be, organized in a manner that facilitates effective management and use of resources. The flexibility to mobilize resources quickly to take advantage of new research findings is of paramount importance.

The Program Strategy describes the minimum number of scientific approaches needed to accomplish the goal. However, all approaches or approach elements may not be given equal support. Priorities will be set by the Deputy Administrator of ARS after he weighs the availability of resources, needs of agriculture, scientific progress, and other criteria. The Administrator will ensure that the priorities are consistent with the goals of the Department. The highest priority portions of the Program Strategy will be included in the Six-Year Implementation Plan for execution by line managers and scientists. In this manner, ARS will help ensure that the best possible science is available to support agriculture. At all times, the ARS will coordinate its efforts with the State Agricultural Experiment Stations, industry, and others who conduct research on these or similar objectives to help ensure that the efforts are complementary. Meeting the research needs of action agencies and policy groups within USDA will have high priority within all six objectives.

**Objective 1**
**Develop the Means for Managing and Conserving the Nation's Soil and Water Resources for a Stable and Productive Agriculture**

Natural resources are the foundation of agricultural productivity. The United States has an abundance of productive soil, water, and related air and climatic resources, but the rate of increase in agricultural productivity apparently is declining. Several causes for that decline are related to the quantity and quality of our natural resources. Erosion, a major problem on nearly one-third of our Nation's croplands, not only destroys inherent soil fertility and productivity, but also pollutes water supplies and fills reservoirs and lakes with sediments that are laden with chemicals and nutrients. Of our rangeland, 60 percent is in only poor to fair condition and produces less than half its potential. Ground-water supplies are being depleted in large areas of the Southern Plains and the Southwest. Increased salinity results in costs to both agriculture and municipalities; in the Colorado River basin alone, damages were estimated at $53 million in the 1973 but are expected to reach $150 million annually by the year 2000 unless salt loading can be controlled. Flood damage to downstream property, estimated at $3.4 billion in 1975, is also increasing. Evidence indicates that air pollution reduces productivity more than previously suspected, and damage in the Ohio Valley alone is projected at $8.3 billion by the year 2000. About 3 million acres of farmlands, nearly one-third of which is prime land, is diverted to nonagricultural uses each year. Water, too, is diverted from agricultural to urban and industrial uses, and competition for water is increasing.

We have recovered some of the productivity lost because of damage to our natural resources in the past by investing capital in conservation practices and irrigation and drainage systems and by applying new agricultural technology. Millions of acres of croplands have been improved or reclaimed by the use of lime and fertilizers, soil conservation, and improved water management. Those same technologies, however, along with improved crop varieties and pest control, tend to mask the continuing degradation of

our soil, water, and air resources. Eventually, those technologies will not compensate adequately for the losses in productivity that result from resource degradation, either because of physical limitations—such as decreasing soil depth—or because of economic limitations caused by the high costs of fertilizer, fuel, and other inputs.

Recent resource assessments by USDA, Congress, and others indicate that the United States is reaching the limit of additional land and water supplies that can be developed economically. Among the factors limiting that development are the high cost of energy, high interest rates, and climatic and soil constraints. Available irrigation water will decrease in several Western States because of ground-water mining and increased competition from nonagricultural users. Because plants lose such large amounts of water during photosynthesis, agriculture cannot compete with other industries. Agriculture requires roughly 100 times as much water to produce products of a given value as does the nonagricultural sector. Moreover, much of the additional land available for croplands, about 130 million acres, is fragile and highly susceptible to erosion or already produces forage and timber. Most of the sustainable future increases in production must, therefore, depend not on an expanding acreage, but—rather—on protecting, restoring, or improving soil productivity, improving crop and forage yields, and using existing water supplies more efficiently.

We must develop and adopt innovative and improved approaches to the evaluation and use of resources and to other factors that are critical to productivity if we are to sustain, much less to increase, the agricultural productivity of our resources. Research findings for use by farmers and ranchers, Extension personnel, private industry, action agencies such as the Soil Conservation Service, and many others are the key to new technology for achieving our goal. The research priorities for the Nation that recently were identified by about 100 of the Nation's leading conservationists emphasize long-term national needs, particularly research concerned with the care and maintenance of our soil and water resources. To meet those research priorities, we must increase our commitment to basic research to restock our storehouse of fundamental knowledge.

**Approach 1.1**

**Develop the Technology for Assessing and Predicting Long-Term Changes in the Quantity and Quality of Soil, Water, and Air Resources Available to Agriculture.**

**Approach Elements**

**1.1.1** *Develop improved techniques and systems for assessing, predicting, and monitoring changes in the productive capacity of land and soil resources.*

**1.1.2** *Develop improved techniques for assessing and predicting water supplies and their quality.*

**1.1.3** *Develop improved techniques for assessing and predicting the effects of weather and air quality on agricultural productivity.*

Our future food-production systems depend upon continuing supplies of fertile soil, good-quality water, clean air, and a favorable climate for plant and animal growth. The supply of natural resources available to the United States for plant and animal growth is finite, and we must take steps now to provide for continued availability and sustained productivity of those resources for future generations.

We urgently need improved technology for assessing our present land resource base and for defining its inherent productive capacity as the basis for development of optimum conservation practices and sound national policies on the management of croplands and rangelands. The United States has about 10,000 kinds of soil that differ in their physical, chemical, and biological properties and in their responses to cultural inputs. Perfecting and using new techniques, such as remote sensing and computerized data collection, to measure those properties and assess their importance can speed information flow and reduce costs. The current system of soil classification provides data and an initial framework for developing the systems needed for measuring and comparing the effects of different management practices on erosion and productivity for diverse soils, climates, and topographies.

We also need improved technology for assessing changes in the quantity and quality of water resources. As the competition for water grows, accurate and timely information about changes will be vital for making the best use of that resource, which generally is the most limiting factor in agriculture. Only one of many examples is the need to assess the effectivenss of action programs for reducing salt loading in the Colorado River. Better management of our water resources requires improved technology for determining the spatial and temporal distributions of precipitation and for evaluating their effects on the quantity and quality of surface and ground-water supplies. Except in areas with large ground-water supplies, climatic factors largely determine water supply for agricultural production. Variations in weather from year to year modify crop productivity, but long-term climatic differences among physiographic regions are largely responsible for regional differences in soil productivity. Technology for accurately assessing the effects of weather on croplands and rangelands must be improved so that conservation and production strategies at farm, State, and national levels can be optimized.

Recent research has shown that some air pollutants, such as ozone, always reduce crop yields. Sulfur dioxide may either decrease or increase yields and soil productivity, depending upon its concentration in the air and the buffering capacity and nutrient status of soils. Increases in carbon dioxide consistently increase crop yields in greenhouse and growth chambers. We need technology for assessing the long-term effects of projected changes in the concentration of those atmospheric constituents on crop and soil productivity.

Improved technology, such as remote sensing, also is needed for monitoring changes in land use, soil and crop status, and soil- and crop-management practices and for assessing their effects on overall productivity. Improved technology will enable more accurate predictions of national and global production of key agricultural commodities and provide early warning of commodity shortages. Those predictions, in turn, will permit better management of our resources, provide useful marketing information, and aid in the development of sound production and marketing policies.

**Approach 1.2**

## Provide the Technology Needed for Improving, Protecting, and Restoring the Productive Capacity of Agricultural Soils.

### Approach Elements

**1.2.1** *Develop cost-effective conservation technologies for controlling soil loss from croplands and rangelands.*

**1.2.2** *Devise methods for maintaining and improving soil fertility and the chemical and biological properties of soils for optimum crop production.*

**1.2.3** *Devise techniques for improving, maintaining, or restoring the physical conditions of soils that are needed for optimum crop production.*

**1.2.4** *Devise methods for safety and efficiently recycling municipal and agricultural wastes through croplands.*

Soils, the reservoirs that store the water and plant nutrients that are needed for crop production, also provide the chemical, physical, and biological environment for seed germination, plant establishment, and root growth. Because erosion of soil impairs those functions, we need a fundamental understanding of the physical processes by which wind and water erode soil. We need an integrated research program as a basis for developing highly efficient, cost-effective systems of tillage and conservation practices for control of wind and water erosion. Those systems must be tailored to the specific requirements of each of the many combinations of soils, crops, and climatic zones in the United States.

We must also improve the practices for restoring the fertility of eroded, mined, and marginal lands, as well as for maintaining the fertility of prime agricultural lands. We should direct substantial research effort toward the management of fertilizers. Increasing the efficiency of nitrogen fertilizer from 50 to at least 75 percent would help reduce the impact of the escalating costs of agricultural chemicals on farm income. Enhancement of nutrient availability in soil, of nutrient cycling from agricultural and other wastes, and of the biological environment in soil also could improve fertilizer-use efficiency. Biological nitrogen fixation can reduce the need for fertilizer nitrogen in some cropping systems. To ameliorate the negative effects that adverse chemical and biological conditions in soil have on the productivity and nutritional quality of plants, we need a better understanding of how minerals, including toxic elements, move from soils into plants. We also need to study how pesticides affect the biological properties of soils and their ability to cycle and release plant nutrients. Large quantities of crop residues adversely affect plant growth by releasing phytotoxic compounds during decomposition; those reactions must be understood for effectively managing minimum- and no-till systems. The development of basic knowledge of soil-plant relationships is one key to future technology for improving soil productivity and eliminating barriers that limit crop yields.

Adverse soil conditions such as low water-holding capacity and permeability, compaction, low temperature, and deficient aeration often limit production. Such conditions could be corrected by improved soil-management systems, including conservation tillage and crop-residue management. However, we need basic studies on the causes of poor

soil conditions and on machine-soil dynamics as a basis for defining optimum conditions for the root zone and for designing practices that will ameliorate adverse soil conditions. We also need to better understand soil microbiology and chemistry so that we can specify safe and efficient practices for recycling municipal and agricultural wastes through croplands. Properly used, those wastes could enhance the productive capacity of soils. The recycling of wastes could salvage valuable water and nutrients and provide organic matter to improve the chemical, physical, and biological properties of soils.

## Approach 1.3

**Develop Improved Water-Management Systems and Practices To Achieve Effective and Efficient Use of Water Resources.**

**Approach Elements**

**1.3.1** *Optimize the use of water by plants in irrigated and nonirrigated croplands and rangelands to improve and stabilize productivity.*

**1.3.2** *Develop methods for increasing, conserving, and managing water supplies available for agriculture, for improving water quality, and for reducing cropland damage from flooding.*

**1.3.3** *Improve technology for storing and distributing water supplies efficiently and for improving irrigation, drainage, and salinity-control systems and practices.*

Water is a key resource for agricultural production, and crop yields are reduced more frequently and severely by water stress than by any other environmental factor. Of about 800 million acre-feet of water that evaporates from U.S. croplands each year, precipitation supplies 700 million acre-feet and irrigation supplies 100 million acre-feet. About 20 million acre-feet of the water used for irrigation is from ground-water reserves, and about 70 percent of that water is drawn from the Ogallala aquifer in the Southern Great Plains, which now supports about 20 percent of the U.S. crops that are exported. Large amounts of water are used by nonagricultural trees and plants, lost by evaporation from lakes and reservoirs, or discharged into the ocean in water-short areas of the arid Southwest. For example, phreatophytes, such as salt cedar, consume an estimated 25 million acre-feet of water annually, of which two-thirds could be conserved for agricultural use. Annual evaporative losses from lakes and reservoirs in the arid West total more than 16 million acre-feet. Several million acre-feet of moderately saline water that could be used for producing salt-tolerant crops is now discharged to salt sinks or to the ocean each year. In the future, we will need to manage water much more efficiently than we do now.

The development of technology for increasing water-use efficiency of crops and ranges (production per unit of water consumed) by 25 to 50 percent during the next two decades requires an integrated program of fundamental and applied research directed toward a better understanding of the response of both irrigated and nonirrigated crops to water stress at various growth stages. Also needed is improved technology for increasing storage of rainfall and snowmelt in soils through such means as controlling runoff, increasing infiltration, and reducing evaporation. Such technology is crucial for high production of rangelands and of dryland crops. By using available water supplies more

efficiently on croplands and rangelands, we can increase total crop and livestock production, reduce the year-to-year variations in yield caused by droughts, and reduce production costs on irrigated lands.

The quantity and quality of water supplies for irrigation and other uses depend upon the management of complex watershed systems. We need to develop an integrated research program on effectively managing and, in some cases, increasing the yield of water from croplands and rangelands by improved management of snow and vegetation. We also need to develop improved low-cost structures and practices for control of flooding, ground-water recharge, water quality, and reservoir sedimentation. We need improved technology for economical water harvesting and runoff farming in arid areas. Particularly needed is improved technology for predicting—for major physiographic areas—the effects of land use and land treatment on water yield and quality, ground-water recharge, base flow, and the frequency and severity of flooding.

Of the water diverted for irrigation, nearly 26 million acre-feet is lost annually by seepage in conveyance systems and a similar amount is lost to deep percolation and surface runoff. Some of that water is recovered for reuse in irrigated valleys, but most of the loss from irrigated areas that are adjacent to oceans, inland seas, and salt sinks is permanent. Essentially, all deep percolation from excess water applied on irrigated lands that are underlain by deep, dry sediments is unavailable for future use. We need to develop low-cost methods for controlling seepage and improving the efficiency of water-distribution systems. We also need improved systems and operating criteria that will enable project managers to deliver, and farmers to use, precisely the right amount of water at the right time.

Improved drainage technologies are also needed to avoid overdrainage of coarse-textured soils, minimize crop stress caused by excess water, improve trafficability, prevent salinization of irrigated soils, and increase the production potential of cold, wet soils. Declines of investments in cropland drainage in recent years could be a significant cause of reduced soil produtivity.

**Approach 1.4**

**Develop Subsystems and Models That Integrate the Use of Soil, Water, and Air Resources for Optimum Management of Major Land Resource Areas.**

**Approach Elements**

**1.4.1** *Develop systems and models for designing resource management strategies that optimize agricultural production and resource conservation.*

**1.4.2** *Develop systems and models for designing resource management strategies that will satisfy the needs of nonagricultural resource uses.*

**1.4.3** *Develop systems and models for designing resource management strategies that are compatible with environmental quality goals.*

Objective 6 describes user-oriented systems and models that optimize the management of land, germplasm, energy, and other resources for efficient and effective production. Models and subsystems should be developed for the simulation of alternative ways to manage each of the variables. Because the soil, water, and atmospheric components of the agricultural system are so intimately intertwined, the management of one component without influencing or considering the influence of the other components is practically impossible. For example, water and air occupy the airspace within soil in reciprocal proportions; the wetter the soil, the less air it contains, and vice versa. The water content of soil has a major influence on soil temperature.

Some plant nutrients remain dissolved in the soil water and, therefore, move with it. Other nutrients, as well as most organic pesticides and heavy-metal contaminants, are strongly adsorbed on the surfaces of soil particles and, therefore, move only slowly with the soil water. Because the surfaces of clay particles within the soil carry net electric charges, they participate in important chemical reactions. The chemical and physical properties of soil, along with its contents of water and air, largely determine its biological capacity. Plant roots are the most important biotic systems in soils, but microorganisms are important in fixing nitrogen from the air into a form usable by crops, in recycling nutrients from crop and other residues and, in some instances, in facilitating nutrient uptake by roots. Simulation models can be used in predicting the effects of different management practices and in designing improved practices for producing crops and protecting water quality.

In general, agriculture must adapt to, rather than manage, weather and air quality; soil capacity influences the success of that adaptation. Deep, porous soils that effectively absorb and store rainfall are less vulnerable to drought than are shallow soils. Soil capacity, a primary factor in determining fertilizer requirements and stability of crop production in rain-fed agricultural regions, is reduced by soil erosion. Frequent irrigation and fertilization compensate for reduced capacity of the soil to store water and nutrients, but at a cost. We need to develop new and improved management systems for conserving resources and optimizing their use for the long term. Farmers and ranchers control more of our environment than does any other group of people, and they must have the knowledge and techniques to manage the environment wisely.

## Objective 2
## Develop the Means for Maintaining and Increasing the Productivity and Quality of Crop Plants

Projected long-term demands for the production of our major crops cannot be met with current yields and, for some crops, could not be met even with the highest experimental yields ever achieved. Meeting those demands is as important and as challenging as providing for national defense, finding new energy supplies, and solving other national problems. We must not only meet our own needs for adequate and nutritious food, but also contribute to the nutritional needs of developing countries until they can grow their own food. Further, sales of food and other agricultural products to industrial nations provide markets for farmers and help balance our foreign trade deficit. We do not know that the projected demands can be met, but, to have the best chance, we must develop strategies for breaking down some fundamental barriers that limit crop productivity. We must also explore possibilities of developing new crops and better methods of controlling the losses from all of our crops.

The foundation of crop productivity is the inherent genetic potential of the plants, themselves. Essentially all the crops we grow and use for food and fiber originated outside the United States. Thus, to ensure a full complement of genetic potential and diversity, and to protect against the kind of vulnerability we experienced with the southern corn leaf blight in 1970, we must have programs for the systematic introduction, evaluation, and development of crop germplasm. As the countries where our crop plants originated develop economically and adopt modern varieties of those plants, folk varieties and wild types are being lost. Once lost, plant germplasm cannot be reconstructed and sources of resistance to disease epidemic or extreme drought could be lost forever. Diverse sources of germplasm also exist for beneficial insects, micro-organisms, and other useful biological materials. Such organisms and materials often hold the key to biological control of pests, and some could supply genes for totally new biotechnologies.

Genetic composition is expressed through its interactions with the environment, including weather, soils, diseases, insects, and many other variables, and many sources of germplasm must be evaluated and screened for use in breeding programs. Then, genes that exhibit desirable traits must be characterized, classified, and preserved. Knowledge of biosystematic or taxonomic relationships within the plant and animal kingdoms is essential for both breeding and pest-control programs. We must make this continuum, from source to end use, of plant genes fully functional and maintain balance to improve productivity, quality, and other desired characteristics of crops. The ARS plays a major role in this continuum and, in a sense, is the steward of the Nation's crop germplasm. A prominent ARS geneticist summarized succinctly, as follows: "When embarking on a voyage into a future as uncertain as ours, we must be sure to take along our seeds."

Anyone who gardens knowns the complexity of growing crops. After selecting the best hybrids or cultivars for their climates, farmers face a multitude of decisions for each crop throughout the growing season. They decide, for example, time of planting, spacing of the rows, depth of planting, and number of seeds per acre. Later, they decide how much and when to fertilize, irrigate, or cultivate. Critical decisions also must be made about harvesting. After harvest and before replanting, they must decide the timing and kind of primary tillage needed to protect the soil and prepare for the next crop. Throughout the year, farmers also must select the materials and methods that will best protect crops against weeds, insects, diseases, and other pests that can rob them of all profits. Nearly all of those activities are interrelated and must be scheduled carefully to produce top yields and quality. One mistake often can make the difference between profit and loss. Finding the best combinations of all those practices for each crop and climatic zone is a formidable research task that requires close coordination and working relationships among scientists in ARS, in State Experiment Stations, and in industry. As the limits of productivity are approached, we must increase our basic and applied research to develop cultural and management practices that will consistently produce high yields. Those practices must also be cost-effective.

In the United States, pests destroy one-third of the potential harvest, or about $35 billion worth of products. Pests are legion and include about 10,000 species of insects, 8,000 fungi, 2,000 weeds, and other assorted organisms. To increase productivity, we must control pests. However, control is complex and costly, and experience indicates that it will become much more difficult as we try to wring higher yields from the land. We often control one pest only to find that another prospers in its ecological niche. Organisms may develop resistance to chemicals. Many pest-resistant crop varieties become obsolete in only 3 to 10 years because the mechanism of resistance is overcome by new strains and biotypes of pests. Just to stay even, researchers must race to develop new varieties and protection technologies. We will need totally new approaches to crop protection if we hope to permanently manage the competition from weeds, diseases, insects, nematodes, and vertebrate pests. As growers adopt new technology and practices, such as minimum tillage, scientists are challenged to develop new methods for control of predators and weeds. When farmers convert from a conventional sequence of practices—crop, cultivate, fallow—to minimum-tillage practices, the land's ecology undergoes ma-

jor changes. Weeds, diseases, and predators that were of no economic significance under conventional practices can become so competitive that traditional practices and plant germplasm will no longer protect yields. Then, scientists must develop new, cost-effective materials and methods to meet the new needs.

We also must try to reduce the costs of pest control that now total about $10 billion per year. Another important concern is the prevention of the potentially adverse environmental effects of both the pests and the methods used to combat them. To deal effectively with those and other concerns, we will test alternative courses of action by computerized systems analysis. For example, we will develop and study subsystems for individual crops and pests and then integrate those subsystems into multiple-crop and multiple-pest systems. Thus, by simulating complex systems, we will be able to predict their biological and physical effects on plants, pests, and the environment and to select the best course of action. Systems analysis will also be needed to identify the barriers, in addition to pests, that limit crop productivity. As an example, such analysis might help us to identify the factor that now limits plants' use of available solar radiation to only 1-2 percent, although the estimated potential is closer to 10 percent.

The need for more emphasis on basis research permeates all aspects of crop productivity. During the past decade, knowledge of and new techniques for manipulating the genetic composition of micro-organisms have advanced dramatically. Those advances strongly suggest that genetic manipulation of higher plants could open the door for totally new kinds of biological materials and technologies. That opportunity must be explored, and exploited if possible, through basic research to determine the ways in which genes code for inheritance, genetic messages are expressed in basic processes, and environment modulates genetic expression. Basic knowledge concerning such factors will be needed if we are to break through the limits on productivity now imposed by pests, finite natural resources, and environmental stresses and are to benefit from the full potential of available germplasm. Examples of possible advances are cereal crops that would provide their own nitrogen through biological nitrogen fixation and plants with a genetic makeup that discourages attack by insects, pathogens, and nematodes.

**Approach 2.1**

**Broaden the Germplasm Resources of Plants and Beneficial Organisms To Ensure Maximum Genetic Diversity for Improved Productivity.**

**Approach Elements**

**2.1.1** *Develop an understanding of the taxonomic relationships among plants, beneficial organisms, and pests as the basis for research to enhance crop production and protection.*

**2.1.2** *Collect, evaluate, preserve, and make accessible new sources of germplasm of plants and other organisms and assess their potential for meeting agricultural and industrial needs.*

**2.1.3** *Collect, evaluate, preserve, and distribute germplasm of plants and beneficial organisms and of strains of pests that are valuable in pest-management programs.*

Plant germplasm is the base for productive agriculture. It is the genetic raw material that breeders use to develop new, superior crop varieties that can ensure a stable, plentiful supply of high-quality food, feed, and fiber. Only a broad base of plant germplasm can provide the genetic diversity that farmers and public and private plant scientists need to improve the quality and productivity of crops and to minimize their vulnerability to biological and environmental stresses. Crops become vulnerable when stresses from diseases, insects, drought, or temperature extremes exceed the crops' ranges of tolerance or resistance to such factors. The results can vary from localized yield reduction to disastrous crop failures over large areas. Protection from crop losses through control of biological and environmental stresses is far more difficult and costly than is protection through increased genetic diversity among varieties of a given crop. In the former method, we attempt to change the environment to meet the needs of the crop; in the latter, we attempt to change the crop to cope with the environment. We must, therefore, broaden the genetic diversity of crops throughout their production areas by developing—from an array of genetic populations—cultivars that are alike in their productivity, but different in their sources and ranges of tolerance to one or more stresses. Such cultivars could reduce the likelihood of epidemic losses.

An area of special need is a systematic exploration of the plant world for potentially valuable new crops and sources of raw materials for industrial and medical uses. Of the more than 300,000 plant species that nature offers, we now use only about 150 in agriculture. No one knows the potential of most of the neglected plants for tolerance to environmental extremes or for producing needed oils, proteins, gums, waxes, drugs, or other useful materials. The potential of those plants for producing strategic materials and making the United States self-sufficient must be assessed.

Similarly, the world offers a vast resource of diverse germplasm of beneficial parasites, predators, micro-organisms, and nematodes. Judicious introduction of selected species, varieties, and strains of organisms from those sources has led to the control of some pests and a significant reduction in production costs. The use of biological control practices as part of our integrated pest management (IPM) strategy holds great promise for the future.

Taxonomic services and research provide fundamental knowledge for basic research in the protection and production of animals and plants. Taxonomy (or systematics) is essential in the research and development of biological control, IPM, regulatory and quarantine activities, alternative and new crops, genetic selection and manipulation, and industrial uses of micro-organisms. Further, the predictive powers of classifications guide exploration and experimentation in the most promising direction; for example, as in the search for natural enemies of pests or for the origin of genetic diversity of potential new crops. Because agricultural, biological, environmental, and health sciences require prompt input of taxonomic data, and because the classification of the estimated 10 million animal and plant species is far from complete, many taxonomic specialists are

needed. Unique and vast resources (specimen reference collections and extensive published and unpublished information) must be physically maintained. Also, the information must be computerized for rapid delivery to and use by a diverse clientele in the development of new research. For efficient utilization and protection of our flora and fauna, we must have the holistic knowledge of their natural relationships that only a solid program of biosystematic research can provide.

**Approach 2.2** **Select and Modify Germplasm of Plants, Beneficial Organisms, and Pests.**

**Approach Elements**

**2.2.1** *Devise new methods for modifying germplasm of plants, beneficial organisms, and pests.*

**2.2.2** *Improve genetic populations of range, pasture, forage, and turf.*

**2.2.3** *Improve genetic populations of field crops.*

**2.2.4** *Improve genetic populations of horticultural and specialty crops.*

**2.2.5** *Improve genetic populations of beneficial organisms, and develop inferior strains of pests that will be useful in pest-management programs.*

The procedures for selecting and modifying plants and beneficial organisms are similar, particularly for range, forage, field, horticultural, and specialty crops. For the purposes of these discussions, in objective 2 no effort will be made to address production or protection procedures on a crop-by-crop basis.

Developing crops that are well adapted to their environments and have desirable nutritional or commercial quality is a long and costly process. Many steps are involved—from the most basic genetic research to maintenance of breeder stocks. Decades may be required to incorporate a desired quality into an adapted crop plant. In contrast, a commercial variety or hybrid may last only a few years before succumbing to a disease organism or insect. For those reasons, plant-improvement programs must have stability and continuity and remain vigorous in the foreseeable future.

Once genetic resources have been screened, genes for the desirable traits that are identified must be combined into improved strains that will be useful to breeders and, eventually, to growers. Resistance to pests, tolerance to cold or drought, high protein content, early maturity, and a host of other desirable features are needed for commercial production. However, those traits rarely are found together, and they may be found in stocks that are unsuited for cultivation. In developmental breeding, which ties together the work of germplasm collection, screening, and gentic analysis, scientists sort—from the many objectives or traits that might be pursued—those with a high probability of success.

Candidate strains and varieties are evaluated through replicated performance trials over several years and several locations. For valid assessments, they must be tested with many combinations of soils, nutrient levels, diseases, insects, weather, cultural practices, and harvesting methods. Only by stringent evaluation of candidates can genetic yield potential keep pace with the increasing demands and complexity of crop production and marketing systems. In recent years, especially with advances in genetic engineering, increased emphasis has been placed on finding ways to shorten the process of crop improvement and to make it more efficient and less costly. However, we should recognize that crop-improvement programs, although slow, have been exceedingly successful and form a solid foundation for the whole agricultural industry.

Emphasis on finding biological agents for pest control has increased. The use of parasites, predators, pathogens, and other kinds of agents as a single tactic or as part of an integrated program offers the potential for pest control that would be economical, energy saving, environmentally safe, and—often—permanent. Such technology is in its infancy, however, and we need much additional research to increase the arsenal of natural enemies. Expanded foreign exploration, quarantine research laboratories, and basic ecological studies will be required.

**Approach 2.3**

**Develop Improved Production Practices for Maintaining and Increasing Crop Productivity and Quality and for Reducing Costs.**

**Approach Elements**

**2.3.1** *Develop knowledge of basic plant growth and development processes of crop species and of micro-organisms of agricultural importance.*

**2.3.2** *Develop basic ecological principles and improved cultural and management practices for range, pasture, and forage.*

**2.3.3** *Develop basic ecological principles and improved cultural and management practices for field crops.*

**2.3.4** *Develop basic ecological principles and improved cultural and management practices for horticultural and specialty crops.*

**2.3.5** *Develop basic principles for and improved methods of pollination and honey production.*

**2.3.6** *Discover principles for and develop criteria and specifications for improving the efficiency of agricultural production and protection equipment and practices.*

Production research is the essential step through which basic knowledge and germplasm resources become useful on the farm. In the production phases of agriculture, genetically controlled biochemical and biophysical processes are expressed as leaves, flowers, or fruit in the conversion of solar energy, soil, air, and water into food and fiber. The purpose of crop-production research is to identify major cultural problems and limitations and to develop practices that solve or circumvent them. Such research requires

knowledge of the basic plant processes that are responsible for the growth and development of plants, as well as close coordination among plant breeders, engineers, entomologist, pathologists, soil scientists, and others. This research is concerned with all aspects of production—from the planting of viable seeds to seedling establishment, plant flowering, and harvesting of vegetative portions, seed, or other crop products. Both quantity and quality are important. For some crops, pollination by bees or other insects is essential, and honey is a valuable byproduct of pollination.

Production research must deal with many variables, most of which interact. Some of the major variables are tillage practices, crop varieties, row widths and planting density, time of planting, fertilization and irrigation (both timing and amount), pest-control methods and practices, time and methods of harvesting or grazing, and—most influential of all—the weather. Many cultural practices are used even for a single crop in the United States, and finding the best one(s) is an enormous task. Quality, especially in food crops, is often as important as is quantity of production. The payoffs, however, are high. Cash receipts totaled nearly $70 billion for the crops produced in 1980, despite losses of about $20 billion caused by one of the worst droughts we ever experienced. However, losses would have been much greater without the production technologies and superior germplasm developed through research.

To meet projected demands for crops and to reduce the costs of producing them, we will need to expand production research. As new crop varieties and hybrids become available, the best combination of practices must be found. A particular opportunity for the southern half of the United States is the use of double cropping to take advantage of the long growing season and high rainfall in the Southeast. Major research needs are the development of cultural practices for safe use of erosive and other marginal lands and the restoration of the 60 percent of our rangelands that is in poor to fair condition. In that research, consideration must be given to many kinds of equipment—planters, cultivators, sprayers, fertilizer spreaders, harvesters, and primary tillage machinery. As farming becomes more complex and precise, so do the machinery and practices for delivering needed inputs at the proper times, rates, and combinations. Researchers must help determine design criteria and specifications so manufacturers can produce better equipment for agricultural production and protection, and farmers can reduce their production costs.

**Approach 2.4**

**Discover Principles and Develop Improved Methods for Reducing Crop Losses Caused by Weeds, Diseases, Insects, Nematodes, and Other Pests.**

**Approach Elements**

**2.4.1** *Develop knowledge of growth, development, and behavioral and population processes of insects as a basis for discovering control principles.*

**2.4.2** *Develop knowledge of etiology, epidemiology, and pathogenicity of plant pathogens as a basis for discovering control principles.*

**2.4.3** *Develop knowledge of growth, development, and behavioral processes of nematodes as a basis for providing control technology.*

**2.4.4** *Provide technology for protecting range, pasture, forage, and turf from losses caused by insects, nematodes, pathogens, and other pests.*

**2.4.5** *Develop principles for protecting field and horticultural crops from losses caused by insects, nematodes, and pathogens.*

**2.4.6** *Develop knowledge of the basic biology of weeds determining their vulnerability to control.*

**2.4.7** *Develop control technology for reducing losses caused by weeds in forage crops, pastures, rangelands, turf, aquatic environments, and noncroplands.*

**2.4.8** *Develop control technology for reducing losses caused by weeds in field and horticultural crops.*

**2.4.9** *Develop fundamental principles of biological control for pests of crop plants.*

**2.4.10** *Discover principles and develop agricultural chemical technology for reducing crop losses and for modifying plant growth for improved crop protection and production.*

**2.4.11** *Develop fundamental principles for the control of vertebrate pests.*

Crop losses caused by pests of various kinds are estimated at $30 to $40 billion per year, plus another $10 billion spent in efforts to control them. Roughly 10 percent of those pests are perennial problems of economic significance. Experience suggests that the difficulty of protecting crops increases as production practices become more sophisticated and intensive. An example is the serious weed problem now appearing in minimum-tillage and "no-till" systems. We can expect many kinds of pest problems in double-cropping systems, especially those coupled with tillage methods that leave crop residues on the soil surface. Unless we can markedly improve our understanding of the growth, development, and behavior of pests, opportunities for major improvements in crop productivity and erosion control will be severely limited.

The magnitude and complexity of the task facing researchers and action agencies are illustrated by the large numbers of pest species of economic significance. Consider, also, that some pests attack several crops—or one crop may be attacked by several pests—and that the soils and weather, along with fertilization and other cultural practices that control the growth and interactions of the pests and crops, have many variables. Those variables and the ability of pests to adapt rapidly to changes in their environment explain the short utility—possibly only 10 years or less—of control practices or resistant crops. The research task is not only complex, but also apparently never ending.

To gain some control over pests, we need research programs with the highest degree of innovation and sophistication. The programs must extend from the most basic studies at the cellular and molecular levels to large-scale pilot studies in the field. We must find better ways to follow the life cycles and migration patterns of pests, to mathematically

describe their growth and development as functions of temperature and other key variables, and to monitor and assess population increases and damages. Then we can develop improved technologies—both chemical and biological—that will interrupt the growth of pests at strategic times and prevent their buildup to economically damaging levels. Such technologies must be developed for each crop and each pest. No one practice or management system can suffice, although IPM systems hold great promise for some combinations of crops and pests.

Vertebrate predation causes large losses to agricultural products—both before and after harvest—in the United States and abroad. Continued research effort must address those losses. Coyotes and birds—along with rats and many other rodents—soil, kill, consume, or devalue products or increase operating costs at many levels of the agricultural production, distribution, and marketing systems. Efficient, safe, economic controls must be devised. Through research, new technology will be made available.

Scientists think that research has a high probability of success, not only for cutting crop losses, but also for reducing control costs and for preventing potentially adverse side effects from pesticides. Certainly the potential benefits are great—$11 billion annually for improved weed-control measures alone. Research on the control of crop pests also has significant indirect benefits in protecting people and animals from insects and the diseases they carry, from allergenic and toxic plants, and from other pests. Also important is the support that the research provides for the action programs of several agencies, most notably the Animal and Plant Health Inspection Service (APHIS) of USDA.

**Approach 2.5**

**Develop Improved Methods for Integrating the Crop- and Pest-Management Practices Needed for Higher and More Stable Levels of Crop Production.**

**Approach Elements**

**2.5.1** *Develop the means for assessing crop conditions, and identify the factors that limit yields of major crop commodities.*

**2.5.2** *Develop growth and management models for optimum production of crop commodities.*

Crop production is one of our most complicated activities. Most industrial commodities are produced in factories with controls and checks at every step. In sharp contrast are the farms with no control over such main variables of production as sunlight, rainfall, temperature, and wind and only limited control over many of the pests that limit production. Knowledge is the key to dealing with such uncertainty and risk. With precise knowledge of the way crops and pests grow and interact with each other and the environment, we can identify limiting factors. We can also build predictive models to help farmers respond to pests or adverse weather with management practices that will conserve inputs and maximize farm profits.

In this approach, the data from the basic and applied research described in the other approaches in objective 2 are incorporated into subsystems and simulation models that are useful to both researchers and producers. Those subsystems also serve as components of the complete agricultural systems described in objective 6. As one example of the need for such systems research, no one knows why average farm yields of several crops peaked years ago or has identified the barriers that limit further increases. To find the reasons and identify the barriers, we need to measure and analyze the relationships of crops and pests to each other and to environmental factors such as light intensity, humidity, temperature, soil fertility, and soil moisture. As one author stated recently, "Only to the extent that we can describe productivity in terms of the mechanisms that control photosynthesis and growth can we bring productivity improvement out of the dark ages of pure empericism."

Simple, quantitative models that incorporate data from broad agricultural and economic sources are becoming powerful farm-management tools for optimizing production. They can be used to determine optimum rates of fertilization, times for spraying insects, and times for and amount of irrigation, as well as to guide managers in other critical decisions. Models also can be used to help identify research opportunities and critical field experiments that are needed for each combination of pest and crop. The key in this approach is the integration of our knowledge of crop plants and of the pests that limit their productivity. New and improved IPM systems are especially needed for optimum control of pests of all the major crops.

## Objective 3
## Develop the Means for Increasing the Productivity of Animals and the Quality of Animal Products

The availability of a vast array of foods from animals helps make Americans among the best fed people people in the world. Because animals convert plant materials that humans cannot digest to foods of high nutritional quality and monetary value, they are an important link in the food chain. Opinions differ among scientists about the proportion of our diet that should come from animals sources. Of diets consumed by Americans, however, more than 45 percent (by weight) is derived from animals. Animal products supply two-thirds of the protein, one-third of the energy, four-fifths of the calcium, and nearly two-thirds of the phosphorus in the American diet. Foods from animals also are major sources of vitamin $B_{12}$ and important sources of iron, vitamin A, thiamine, riboflavin, vitamin $B_6$, and other essential minerals, micronutrients, and vitamins. As developing countries improve their economies and as U.S. citizens move up the economic ladder, their demand for foods from animals tends to increase. Animals also provide leather, wool, feathers, horn, bone, and biological products, such as the hormone insulin, that are important to human health. Animals are important models for conducting research related to the improvement of human health, are still used in some areas for transportation and power, and provide pleasure for many people. Beef and dairy cattle, swine, sheep, goats, poultry, horses, fish, rabbits, fur-bearing animals, laboratory animals, some beneficial and harmful insects, and predators and other specialized animals that are related to agriculture must be considered in our research strategy. Aquaculture (fish farming) is an emerging area of opportunity for increased productivity and more efficient use of land and water resources.

Animal production is important to the U.S. economy and generates about 52 percent ($70 billion in 1980) of the total farm income. Grazing animals are important in the use and maintenance of the natural resources in our ranges, pastures, and forests. They con-

tribute to resource conservation by producing food from land that is not made vulnerable to erosion by tillage and from land in terrain that is unsuitable for crop production.

Losses from diseases, parasites, pests, and biological and management inefficiencies cause losses to the animal-production industry and to consumers that amount to billions of dollars annually. Research must generate the necessary knowledge and technology for reducing those losses and for supporting action and regulatory agencies of the USDA and other Federal departments in carrying out their responsibilities. Through a combination of research, development, and education, the efficiency of many phases of animal production has increased substantially in the last 20 years. However, as described for crop production, we have reached the limits in many instances, and further progress requires research ranging from fundamental studies of intricate life processes to the development of totally new ways to increase efficiency and productivity. Inadequate basic knowledge is the major limiting factor in improving the efficiency with which we produce and utilize foods and other products from animals. In a conference in May 1980, more than 200 leading scientists, producers, industrialists, consumers, and experts in human nutrition and medicine identified research needs that, if satisfied, would enable agriculture to effectively and efficiently meet future demands for animal products. The approaches and elements listed below are consistent with the priorities identified at that conference.

**Approach 3.1** **Increase the Genetic Capacity of Animals for Production.**

**Approach Elements**

**3.1.1** *Devise optimum selection and mating procedures for obtaining high levels of animal performance and improved product quality.*

**3.1.2** *Devise procedures for selectively manipulating genetic material to improve desired characteristics.*

**3.1.3** *Determine genetic variation in biochemical, physiological, and behavioral traits of animals, and devise ways for using the information to accelerate genetic improvement.*

**3.1.4** *Improve genetic resistance of animals to diseases and internal and external parasites.*

The productivity of farm and range animals is shaped by both their genetic makeup and their environment. Much of the improvement in animal productivity in recent decades has resulted from increased genetic capacity for synthesis of meat, milk, eggs, wool, and other animal products. To genetically improve animals, breeders must identify animals that are genetically superior for given environments. The long gestation, slow rate of maturation, and low prolificacy of large farm animals lengthen the time required for evaluating animal performance. To accelerate progress and reduce production costs, we must establish procedures for identifying animals that are genetically superior without waiting for their full development. Such procedures will require new methods for reliably estimating both the genetic merit of individual animals and the performance of specific matings for the development of alternative systems for selecting and mating animals.

Genetic engineering research could produce techniques for identifying and transferring genetic material between animals and between animals and bacteria. Possibly through cloning and related technologies, genetic copies of superior animals could be produced. Other long-term research is needed on genetic manipulation to produce animals that are resistant to diseases and parasites. If we could identify the genes and their products that make certain animals susceptible or resistant to parasites and diseases, resistance might be bred into livestock.

We must determine, in animals, the effects of genetic variations on hormones, enzymes, and other biochemical regulators of performance and of economically important traits. The genetic control of immune responses, behavior, and resistance to diseases, parasites, pests, and other stresses also must be studied. Of particular importance are genetic influences on metabolism that might be used to regulate the types and proportions of fats, proteins, vitamins, and minerals in animals and in foods produced from them.

**Approach 3.2**

**Improve the Efficiency of Reproduction and Reproduction-Related Biological Processes.**

**Approach Elements**

**3.2.1** *Increase the number of offspring reared per male and female maintained.*

**3.2.2** *Increase efficiency of germ cell and embryo production, transfer, and storage and of techniques for producing more offspring of superior quality.*

**3.2.3** *Increase efficiency and persistence of lactation and egg production.*

The failure of animals to reproduce consistently and prolifically is one of the most costly and production-limiting problems facing our livestock industries. Annual losses from low performance are estimated at $10 to $14 billion, or 14 to 20 percent of the total income from U.S. animal agriculture. The reproductive rate of most animals is 80 percent. A 10-percent increase in reproductive rate would increase efficiency by 6 percent, which alone would save producers about $4 billion annually.

Reproductive efficiency might be improved by increasing twinning in beef cattle, shortening the calving interval in dairy cattle, increasing embryonic survival in swine, and increasing the frequency of multiple births in sheep. We should develop and improve procedures for controlling the timing of ovulation and for synchronizing estrus. Nuclear transfer, semen preservation and predetermination for sex, *in vitro* fertilization, and mechanisms for controlling the fertility characteristics of individual animals also should be emphasized. We must undertake basic biological research on development of the technology for freezing, storing, and then thawing embryos for use in improved technologies for transferring embryos. The answers gained through basic and applied research in all of those areas, and their subsequent use by producers, could significantly advance the genetic and productive capabilities of livestock.

We need a better understanding of the endocrine and neuroendocrine mechanisms that regulate feed-energy conversion and milk-secretion processes and of the hormonal and cellular mechanisms that control milk synthesis. To improve the productive capacity of

turkeys and other poultry, we need similar studies to determine the mechanisms that regulate egg synthesis. Studies are also needed on turkey-semen preservation, sperm transport, ovulation, and oviposition and on their relationship to egg hatchability.

A strong, integrated research program to improve the reproductive efficiency of animals is essential for maintaining progress in the efficient production of meat, milk, eggs, and other animal products.

**Approach 3.3** **Improve Animal Nutrition and Feed Efficiency To Increase Productivity and Product Quality.**

**Approach Elements**

**3.3.1** *Remove nutrient limitations to production.*

**3.3.2** *Reduce losses and inefficiencies in nutrient use, and explore alternative sources of nutrients.*

**3.3.3** *Devise nutritional and physiological means for modifying the rate of synthesis and the composition of animal products.*

Because feeds represent 40 to 50 percent of the total costs in animal production, efficient feed utilization is essential for profitable production of meat, milk, and eggs. We must improve our understanding of the factors that affect nutrient needs; the digestion, absorption, and assimilation of nutrients; and the synthesis of animal products. Any gains made in improving feed utilization by animals and in lowering feed costs will improve the economic viability of livestock producers and lower the cost, to consumers, of foods from animals.

Only through basic research can we understand the metabolic processes through which animals convert feed to meat, milk, and eggs and, through that understanding, develop technology that will enable animal producers to improve the efficiency of the metabolic processes that control the composition of animal products. Although general nutrient needs of animals are known, we now need to know their specific nutrient needs, at various stages of their life cycles, for producing meat, milk, eggs, and wool of the highest quality and in the greatest quantity. As we genetically improve the productivity of animals on farms and rangelands, we must reconsider their nutrient requirements. Maximum animal performance depends upon high feed intake, and we must define the physiological factors that control the appetite of animals in different stages of growth and under different environmental conditions. The effects, on feed intake, of (1) composition and physical state of the feed and (2) physiological factors should be clarified. By understanding the nutritional needs of animals at all times, we can devise improved ways for managing soils, crops, and livestock to meet those needs.

Microbes in the digestive tracts of animals ferment and grow on feedstuffs consumed by the animals and, in ruminants, are responsible for cellulose digestion. Feedstuffs must, therefore, be designed to nourish both the host animal and the desirable microorganisms in the digestive tract. Because cellulose is a major component of many feeds,

we need to understand the factors that limit digestion of cellulose and hemicellulose and the conditions that favor maximum benefits from the micro-organisms in the gastrointestinal tract. Additional research is also needed on chemical and biological procedures that will free, for use by ruminants, extra energy from the lignocellulosic substances in low-quality feeds, forages, and plant residues.

**Approach 3.4**

**Develop Ways To Prevent or Control Losses From Diseases, Parasites, and Toxicants and Other Substances That Limit Animal Performance and Reduce the Quality of Animal Products.**

**Approach Elements**

**3.4.1** *Improve methods for diagnosing and identifying agents that cause losses, and improve methods for assessing those losses.*

**3.4.2** *Establish the roles of environmental stresses and nutrition in losses from diseases and parasites.*

**3.4.3** *Characterize the mechanisms by which animals become infected and are affected by diseases and parasites.*

**3.4.4** *Devise new and improved methods for preventing or reducing death, morbidity, and other losses from diseases and parasites.*

**3.4.5** *Prevent, control, or eliminate losses from natural or synthetic substances to which animals may be exposed.*

Throughout the world, diseases, internal parasites, and toxicants cause major losses and are important causes of low animal productivity. In the United States, they cost livestock producers, and subsequently consumers, an estimated 20 percent of the farm income from livestock and poultry products, or about $14 billion per year. Losses from diseases, internal parasites, and toxicants include death, restricted growth, reproductive inefficiencies, and veterinary costs. Other losses are from "production diseases," which often produce no recognizable clinical signs of disease but do lower productive efficiency. As a class, they are complex epidemiologically and have infectious, toxic, genetic, metabolic, and nutritional etiologies, or combinations thereof. They generally result from several etiological factors that act in concert with environmental and production factors. This class of diseases includes infectious complexes, reproductive disorders, metabolic imbalances, toxicoses, digestive system disorders, nutritional disorders, stress-related syndromes, parasite and insect infestations, and combinations of two or more thereof.

Research is needed to find new and improved methods for identifying losses from diseases, parasites, and toxicants. We need tests for diagnosis of recognized diseases, detection of inapparent carriers, identification of new diseases or sources of loss, and assessment of losses attributable to individual diseases. Rapid diagnosis is critical for treating sick animals early, preventing exposure of healthy animals, and safely moving animals from one farm to another. The identification of new diseases should help control losses from "production diseases" and from reproductive diseases, which often are never identified because the disease-causing agent disappears before its effects are seen.

Research is needed to define the effects, on health, of stresses associated with the environment, disease, and nutrition. We should study the factors that influence infection by disease, including the effects of hormones on the immune system and the response of animals to vaccination. We also should study, at the cellular level, the interactions of disease agents and the control of interactions by hormones and genes. Stresses and nutrition also affect losses caused by parasites, but those interactions are poorly understood. Even more poorly understood are the mechanisms by which diseases and parasites are transmitted, infect animals, and adversely affect their health.

Recombinant DNA technology is expected to revolutionize the production of vaccines and other biological materials that are needed to prevent disease or promote growth. Advantages of the technology are safety of the products and the ease with which abundant supplies of vaccines and materials can be produced. We should thoroughly explore the potential of recombinant DNA technology for producing vaccines and products that stimulate the natural immunity of animals.

Research is needed to determine the toxic, metabolic, and subclinical effects of agricultural chemicals and poisonous plants on livestock and the relationships of those chemicals and plants to diseases and efficiency of production. In that research the risks of undesirable residues in meat, milk, and eggs should be assessed. Further research is needed on medicinals, feed-grade chemicals, antimicrobials, and drugs for prevention and control of disease and/or for increasing efficiency of animal production. Research also is needed to identify plants that may be harmful to animals; to determine their toxic components, mode of action, and possible hazards to public health; and to find means for preventing losses of livestock from exposure to such plants.

## Approach 3.5 — Develop Means for Controlling Insects, Ticks, and Mites That Affect Animals and Man.

**Approach Elements**

**3.5.1** *Improve methods of detecting infestations and assessing losses.*

**3.5.2** *Examine mechanisms by which insects, ticks, and mites cause harmful effects.*

**3.5.3** *Devise new and improved methods for reducing losses from insects, ticks, and mites that affect animals and man.*

**3.5.4** *Integrate control technologies into systems approaches for managing insects, ticks, and mites that affect animals and man.*

**3.5.5** *Develop means for protecting humans from insects and insect-borne diseases.*

In the United States, insects, ticks, and mites that affect livestock and poultry cause annual losses estimated at more than $3 billion. Insects, ticks, and mites also directly affect people by impairing their health and productivity through annoyance, debilitation, and disease transmission. The estimated annual cost of those pests and disease vectors to civilian and military populations of the United States exceeds $1 billion.

A balanced program of basic and applied research should provide the knowledge and technologies that are needed to alleviate those losses. Methods of detecting infestations of insects, ticks, and mites must be improved, and thresholds of economic importance must be determined for species that affect man and animals. Early, accurate detection of infestations and assessment of losses are essential to timely application of control measures. Basic research on the biology and ecology of specific pests is needed to provide the knowledge for designing effective controls. For development of vaccines, we must understand the role of immune systems in the natural and acquired resistance of animals and identify the genetic products and immune-response genes that are responsible.

New and improved methods of reducing losses should be emphasized in research on the chemical control of insects, ticks, and mites that affect man and animals. Genetic methods of altering the pests, themselves, also must be devised through such mechanisms as hybrid sterility, male sterilization, cytoplasmic incompatibility, chromosomal translocations, compound chromosomes, and other genetic anomalies. Special attention is needed to discover and develop effective bilogical control agents, such as pathogens, parasites, and predators. Possibly in studies of animal facilities, water management, or manure disposal, we could develop improved techniques for control. Basic research may reveal either physiological systems that can be interrupted to alter pest behavior or ways for producing new, physiologically active chemicals to control pests. Applied research will be used to combine chemical control, host immunity, genetic control, biological control, cultural control, and novel approaches into integrated systems for the management of insect, tick, and mite populations so they can be maintained below thresholds of economic importance.

A strong research program that provides the means for controlling insects, ticks, and mites that affect animals and man should enable farmers, with the help of such agencies as APHIS, to reduce animal production losses by 15 percent (national total of $450 million per year). It should also provide the means, particularly through the Departments of Agriculture, Defense, and Health and Human Services for reducing direct losses to human health and productivity by 20 percent, or $200 million per year. Potential savings in human life, health, productivity, and well-being are inestimable.

**Approach 3.6**

**Devise Means for Improving and Integrating Procedures and Facilities for Production and Transport of Animals To Increase Productivity, Reduce Costs, and Minimize Stresses.**

**Approach Elements**

**3.6.1** *Assess environmental impacts and shelter needs for farm animals.*

**3.6.2** *Develop facilities and equipment for feedstuff storage, processing, and distribution.*

**3.6.3** *Develop facilities and equipment for improving animal performance and labor efficiency in production systems.*

**3.6.4** *Develop improved facilities and equipment for handling and transporting animals.*

**3.6.5** *Develop systems for managing and using manure efficiently as a resource.*

**3.6.6** *Devise integrated management practices for maximizing animal productivity and product quality, while minimizing stress.*

**3.6.7** *Evaluate, for optimum use of resources, management programs that integrate all productivity elements under various environmental conditions.*

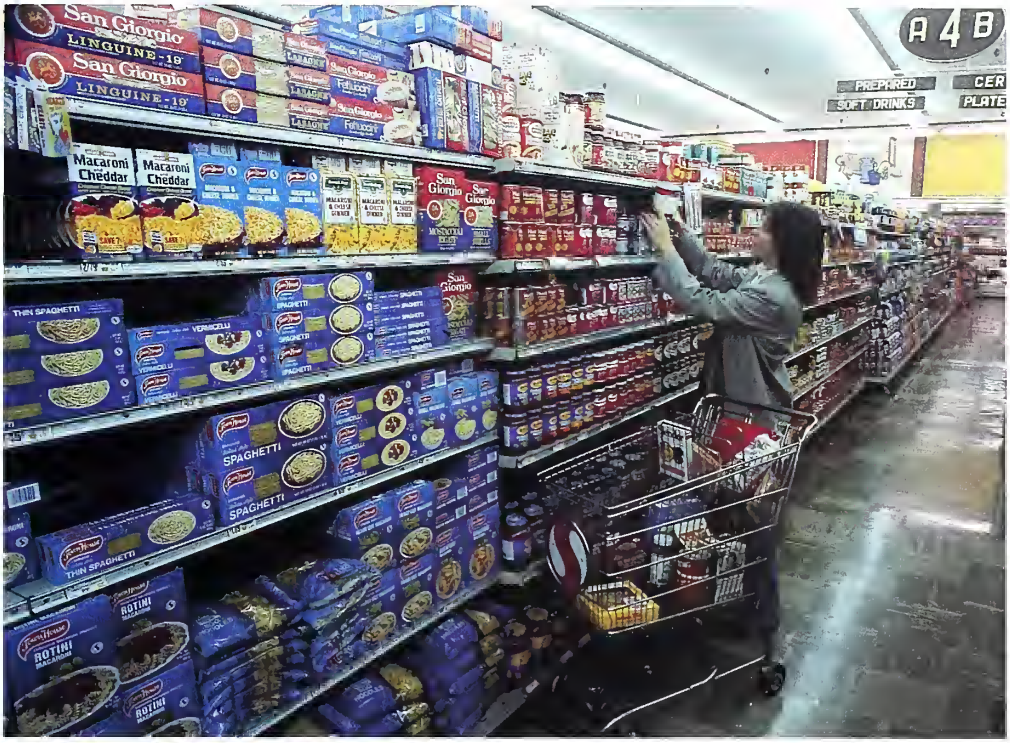
As labor and other costs have risen, animal producers have improved efficiency through better management and the use of labor-saving equipment, and the average size of animal-production units has increased. Millions of dollars are invested annually in animal-production facilities and equipment. For reduction of those costs, research is needed to provide engineering and management technology for modern livestock and poultry farms and to integrate available technologies into efficient systems.

Environmental factors interact to influence animal performance. We should conduct research to define the criteria that are needed for evaluating environmental requirements for optimum animal performance and for designing more effective facilities and equipment to protect animals from weather, insects, diseases, and other destructive influences. Valid models must be developed for assessing environmental impacts on animals and for selecting alternative shelters and handling procedures and equipment for farms, feedlots, and ranches.

We must find ways to increase the efficiency and accuracy of feed preparation, delivery, and utilization by improving the facilities for storage and handling and the controls for blending and dispensing. Automated procedures for collection and analysis of information should be developed that will facilitate daily management decisions on breeding, feeding, housing, and marketing and on control of diseases, parasites, and pests. We must find ways to reduce the losses of animals and animal products during handling and shipping. Another area of opportunity is finding ways to efficiently use the nutrients and energy contained in animal wastes.

Management systems for optimum use of resources must be evaluated for most efficient production of beef and dairy cattle, swine, sheep, poultry, fish, and other economically important species. All aspects of farm-animal production must be integrated into total management systems that provide optimum care for animals, reduce stresses, and improve efficiency and product quality. Integration will involve development and evaluation of computer simulation models of alternative total management systems for the optimum use of biological, physical, and economic resources under the widely different conditions across the United States. Reducing losses of animals to predators is a critical need in some phases of livestock production.

## Objective 4
## Develop the Means for Achieving Maximum Use of Agricultural Products for Domestic Markets and Export




Public benefit from agricultural business depends upon delivery of a dependable supply of food and other agricultural products to consumers through an effective and efficient marketing system and upon an adequate return to farmers who produce the raw products. The economic incentive for engaging in agriculture—the planting of crops and the breeding of animals—lies in the increment between the costs of a farmer's total investment and his total return. That increment, profit, depends heavily upon the marketing system. A myriad of firms, organizations, and individuals pack, process, handle, transport, store, and distribute farm products. In fact, marketing costs accounted for more than two-thirds ($183 billion) of the money spent for domestically produced farm foods in 1980.

The difference between the price received by farmers and the price paid by consumers—the "farm-retail price spread"—has been increasing in recent years and undoubtedly reflects the rising costs of capital, labor, services, and all other inputs that are added, during marketing, to the costs of production. Some added costs do increase value by enhancing the safety, nutrient content, or convenience of food items or the utility of nonfood items, but others reflect the costs of advertising and extravagant packaging. The increasing farm-retail price spread also could indicate declining efficiency in the marketing system. We must pursue research that facilitates the profitable marketing of both the raw agricultural materials and the processed products manufactured from them.

No products of American business are more important to the Nation's economic health than are the exports that earn foreign credits. Among our total exports, agricultural products predominate and indirectly help pay for the oil and manufactured products that we import. Maintaining and enhancing the value of those exports could help achieve op-

timum use of our agricultural product. We should also develop new crops and products for export. We must develop technologies, for all phases of postharvest treatment and for transport, that will ensure delivery of high-quality products to foreign markets. New scientific information about the essential characteristics of agricultural products for export and about the technologies for shipping those products should not only help other Government agencies in establishing standards that meet export goals, but also help industries in developing products and technologies that meet the needs of foreign buyers.

Most agricultural products must be processed or modified in some way before they are marketed and used by consumers. Modifications can range from subtle improvements— for example, removal of green color from oranges— in products that are consumed as harvested to separation into components for direct use or for use in formulations, mixtures, or unique products. The changes may either improve the nutritional, sensory, or functional characteristics of products or improve their safety, durability, convenience, and utility. Conversions of agricultural wastes and residues—and even new crops—into alternative fuels and petrochemical substitutes are examples of processing products into nonfood items. Traditional processing operations include physical, chemical, and biochemical methods. Recent advances in biotechnology open the door for creating totally new kinds of food and nonfood items from agricultural raw materials and for improving the utility of traditional items.

To develop advanced technologies, scientists must first acquire basic knowledge of the chemical and physiological processes and properties of individual commodities and potentially valuable new crops. Certain traits can be used as indexes for objectively and automatically classifying, sorting, and segregating commodities according to their quality, safety, and market value. Those indexes could also be useful as criteria for use by geneticists and breeders in developing genotypes with improved quality.

We often need basic data for improving technologies for preserving and storing agricultural products. The perishability of raw agricultural commodities is a major challenge to the marketing sector and to research. Perishability is manifested in different ways and to different degrees. Each commodity requires specific methods of protection during handling, storing, processing, and retailing to prevent deterioration, loss, or contamination that could be hazardous to consumers. Major factors that influence perishability are damage—from insects, microbes, and physical abuse—and chemical and metabolic breakdown. Those factors cause annual losses of food, alone, estimated at $31 billion. In addition, all the labor, energy, and other resources expended during production and marketing, up to the time of loss, are wasted. To meet future needs for food and fiber at affordable prices, we must find more effective ways to prevent losses.

Scientists also should develop means for enhancing the total market value of the agricultural product. With new technologies, we should be able to increase the marketable portion of the agricultural output, enhance desirable traits, and decrease or eliminate undesirable traits in natural or processed products of plants and animals. We may be able to find new crops or to develop totally new products.

Scientists also are challenged to develop means for improving the overall efficiency of the entire system of harvesting, processing, transporting, and marketing. Inefficiencies in that system could offset potential gains in yield and product quality. We need to identify the costs for labor, time, energy, water, and other inputs that could be reduced and the steps and procedures that could either be eliminated or combined to shorten and simplify the whole marketing process. We need studies of the methods, facilities, and equipment used to handle, process, grade, package, and ship specific commodities and products. In those studies, we should examine the system from the farm through assembly points, processing plants, storage, and delivery. In the analysis of the marketing system, use of computerized information systems and models will help us to identify inefficient steps that should be modified or eliminated.

**Approach 4.1**

**Develop Means for Enhancing the Inherent Properties and Uses of Agricultural Materials.**

**Approach Elements**

**4.1.1** *Characterize the basic, physical, chemical, and aesthetic properties of plant and animal materials that enhance their usefulness.*

**4.1.2** *Identify the biological and biochemical mechanisms, in plants and animals, that affect properties of agricultural materials.*

**4.1.3** *Devise means for regulating and controlling the biological processes that enhance usefulness.*

**4.1.4** *Devise concepts for innovative and improved processes and products.*

For maximum value, farm products must meet market demands for quality and utility. However, we often cannot measure either trait directly and must characterize its associated properties—such as flavor, color, texture, and strength. We need new chemical, mechanical, or electronic methods for evaluating quality and utility objectively.

The basic biological and biochemical processes that function in the cells of growing plants and animals influence the market value of farm products. Those processes respond to nutrients, environment, and cultural practices during production. We must identify the basic processes that are responsible for producing desirable and undesirable properties in the products of plant and animal origin. For effective use of the knowledge of basic processes, we must devise means for stimulating the processes that produce desirable properties in farm products and for suppressing those that produce undesirable properties.

For some commodities, we have developed multiple uses. From corn—which is used primarily as feed for livestock—we manufacture a myriad of breakfast foods, oils, sweeteners, starch, alcohol, and many other products. Processing also enhances the utility of other crops, of which potatoes are a notable example. Processes for flame-retardation and wash-and-wear characteristics in cotton and woolen goods are other examples. We must develop new uses for farm products and new methods for enhancing their value.

We must be innovative in research related to animal products. New concepts of nutrition and modification of dietary habits could affect the markets for products of animal origin. Scientists have successfully produced lean hogs, are reducing the sodium content of processed meats, and have experimentally modified the constituents of milk and eggs. With the basic knowledge of the biological processes by which animals metabolize nutrients into meat and other animal products, and with the means for controlling those processes, scientists might be able to improve the nutritional quality and marketability of products of animal origin. Foreign markets, especially industrialized nations such as Japan, offer attractive possibilities for our products from animals. By improving the technology for maintaining—in meat and meat products—the high quality necessary for expanding foreign markets, scientists can contribute to our Nation's economy. Exporting finished products not only improves our balance of payments, but also creates more jobs at home.

**Approach 4.2**

**Develop the Means for Meeting Foreign and Domestic User and Regulatory Requirements Relating to Toxic Factors in Food, Feed, and Other Agricultural Products.**

**Approach Elements**

**4.2.1** *Identify and, when necessary, develop the means for removing intrinsic toxic factors of practical significance.*

**4.2.2** *Identify and, when necessary, develop the means for removing extrinsic toxic factors of practical significance.*

Safety is important throughout the agricultural system, but it is essential in food. Farm products containing recognized hazards cannot be sold. As a result, producers lose income and the public loses food. Awareness of the importance of safe, highly nutritious foods and safe workplaces is increasing. Throughout production, processing, and distribution, the safety of the food supply is challenged by natural constituents such as enzyme inhibitors, hemagglutinins, goitrogens, and saponins. Processing, cooking, dilution, digestion, and detoxification by metabolism protect us from many natural toxins, but we need information for setting reasonable threshold levels in food and we need to find ways to prevent or control excessive amount.

We could control or eliminate some natural toxins in plant materials that we eat or feed to animals by developing varieties of plants that do not produce toxins. By studying the biochemical processes of cells, we should be able to manipulate the bioregulators of plant metabolism to minimize toxin production. Much of such work will be on crops for livestock feed.

During processing, many compounds—such as salt and sugar—are added to foods. Most traditional food additives are assumed to be safe, but even those can be harmful in excess. Some potentially harmful compounds, such as those produced by browning reactions, can form during processing. Others may result from contamination or may be residues of agrichemicals, antibiotics, or hormones. We must increase our understanding of the toxicology of all potentially harmful compounds and develop methods for detecting and measuring them and their reaction products during processing and storage.

The gastrointestinal illness called "food poisoning" affects as many as 20 million people annually in the United States. Outbreaks continue because (1) producers and consumers are ill informed and do not take known precautions; (2) bacteria, fungi, and viruses that can cause food poisoning are widespread; and (3) we lack basic knowledge about the factors that affect the survival of the organisms and the synthesis of their toxins. To locate and possibly eliminate sources of contamination, we should improve methods for isolating, identifying, and enumerating bacteria, fungi, and viruses that are associated with food. We also should identify—for microbes—the genetic, ecological (physical and chemical), and nutritional factors that interact in foods to favor the development of food poisoning. With that information, we should be able to develop methods that will prevent microbes from growing or forming toxins, or both.

In some years, under some conditions, certain species of fungi invade and produce mycotoxins in such crops as corn, wheat, cotton, peanuts, and tree nuts. Mycotoxins can be ingested with feed and appear in milk and meat. The levels at which mycotoxins become hazardous in food or feed vary among specific toxins produced by different fungi. The Food and Drug Administration of the Department of Health and Human Services has established tolerances for one group of mycotoxins—aflatoxins—in some crops. Using ARS methods, the peanut industry identifies and segregates contaminated peanuts from those that are used directly in foods. For crops that are susceptible to toxin-producing fungi, we must develop sensitive, rapid, and inexpensive methods for sampling and analysis. In assessing the safety of agricultural products, we must identify hazardous etiological agents and evaluate the levels of the hazards to determine whether they have practical importance. For any that are important, we must explore methods for preventing, detoxifying, processing, and grading to eliminate or control the hazard.

Workers who handle farm products can be exposed to conditions that could be hazardous. Byssinosis, for example, is a respiratory ailment that apparently is associated with exposure to cotton dust in the workplace. That association threatens the U.S. cotton industry, and we need scientists in several disciplines to identify the causative factors. Then—by studying all phases of cotton production and processing—they must either try to find cost-effective treatments for cotton or develop handling procedures that would eliminate the problem.

## Approach 4.3

## Develop Means for Reducing or Eliminating Postharvest Losses Caused by Pests, Spoilage, and Physical and Environmental Damage.

### Approach Elements

**4.3.1** *Develop improved methods for controlling losses caused by insect pests.*

**4.3.2** *Develop improved methods for controlling losses caused by micro-organisms.*

**4.3.3** *Develop improved methods for controlling losses caused by internal chemical and biological mechanisms.*

**4.3.4** *Develop improved methods for controlling losses caused by physical forces.*

All agricultural commodities are subject to losses during all stages of the marketing system. The extent of total postharvest losses of food worldwide is not known, but for cereal grains, the worldwide loss probably ranges from 10 to 20 percent. The Food and Agricultural Organization estimated that a 10-percent loss would be equivalent to one-half pound of cereal per day for each of 400 million people. The losses of perishable fruits and vegetables are undoubtedly higher. In the United States, about 20 percent of all food produced each year is lost—a loss that amounts to an estimated 137 million tons valued at $5 billion. Estimates of losses caused by pests, alone, range from 3 to more than 10 percent. A 5-percent loss at 1980 retail prices would amount to $14 billion.

Total losses include those of quality and quantity. Both types of loss can occur during all stages—storage, processing, handling, and distribution—of the marketing system. Losses are caused by physical damage, ineffective procedures, and chemical and biological deterioration—but most commonly by the activities of insects and micro-organisms. Often, losses of a given commodity are caused by the interactions among several causes. Some micro-organisms, for example, do not attack sound fruits but do enter wounds inflicted by insects or by rough handling. Thus, the measures devised for controlling losses also interact and cannot be isolated in either theory or practice.

Refrigeration is the critical factor in preserving our perishable agricultural products and in supporting our modern life style. Low temperatures prevent losses that are caused by either pathogens or biological deterioration and also protect against some insects. Scientists have refined procedures for manipulating atmospheres as supplements to refrigeration, but the optimum conditions—of temperature, humidity, and atmosphere—that are regulated for preservation of perishables must be defined for each commodity. We also must explore irradiation as an alternative means of preserving foods for long periods and for use where refrigeration is not available. Foods in sealed containers that are given sterilizing doses of radiation can be stored at room temperature for years without spoiling, and they are not radioactive.

Many of our present methods for controlling insects and other pests that infest commodities during marketing rely upon chemicals whose effectiveness is declining as resistant strains of pests develop and whose safety is being questioned. We must develop a new generation of pesticides that are nontoxic and persistent. Biological controls, and even an insecticide produced by a bacillus, are available for use in the field. Scientists must search natural sources for repellents and pesticides that would be safe for use on commodities during marketing.

To develop new methods for controlling postharvest losses of agricultural products, we need basic knowledge about the biology and ecology of insects and micro-organisms, about the interactions among them, and about their interactions with their hosts and their environments. We must study the basic processes by which the cells and tissues of biological materials deteriorate—even under optimum conditions. Conversely, we need to understand the mechanisms whereby such materials resist deterioration. To devise procedures for minimizing losses from physical damage, we need to understand the biological nature of physical injuries.

Genetic manipulation offers a promising, long-range opportunity for the development of nonchemical methods for controlling losses of agricultural products. We know that some species, and even some strains of species, are more susceptible to attack by pathogens and insects and to physical damage than are others. In cooperation with geneticists, who enhance production by developing resistant strains of plants and animals, scientists in postharvest technology should study commodities, when they are ready for market, for signs of genetic resistance to factors that cause postharvest losses. The introduction—into plants and animals—of genetic material that would either enhance the resistance of their perishable products to attack by insects and pathogens or delay biological deterioration during marketing could be the most effective and least costly means of controlling postharvest losses. Integrated management systems that include all available means for controlling losses hold great promise for increasing the quality and quantity of agricultural products.

**Approach 4.4**

**Develop the Means for Increasing Efficiency of Systems for Processing, Handling, Storing, and Distributing Agricultural Products.**

**Approach Elements**

**4.4.1** *Identify system inefficiencies.*

**4.4.2** *Devise means for reducing or eliminating inefficiencies.*

**4.4.3** *Devise means for efficiently classifying products for exchange in the marketplace.*

**4.4.4** *Devise means for meeting domestic and foreign quarantine and other requirements that restrict movement and trade of products.*

A recent assessment of business productivity attributed 67 percent of the growth in both total production and gross product per labor hour to advances in knowledge and technology. Of the approximately 30,000 companies (not counting retail outlets) that process, store, and distribute food, only about 100 have research facilities, and the research of each benefits only the owners and customers of that company. Public research benefits all owners and all customers, but Federal and State support for marketing research declined 19 percent between 1966 and 1970, and the scientific workforce declined 15 percent between 1971 and 1980. During the 1950's, agricultural marketing was second only to agricultural production in terms of industrial productivity, whether measured by output/input indexes or by value added to products. Marketing productivity began to decline in the 1960's and now reflects the escalating costs of labor and all energy-related inputs. Through research, we must find ways to reverse that decline. We must also find ways by which companies that process, store, and distribute agricultural products can reduce costs, still maintain or enhance the quality of those products, and improve their competitive position in foreign markets.

We can start with processing—possibly the most expensive function in the marketing system. Processed foods are the principal items in our diet; more than half our food is processed, and about half our meals are eaten outside the home. The food-processing industry is our fourth largest energy user, and the cost of processing has risen with the

costs of energy and other inputs. To compensate for rising costs, we must both improve the efficiency of present processing methods and develop new, better methods.

In basic engineering studies, we must identify and develop technologies that can reduce or eliminate inefficiencies in processing. For example, we can simulate the processing function in computer models and, by systems analysis, detect the steps with the greatest potential for efficiency improvement. On pilot processing lines, we must determine the effects of each processing step on the nutritional value, yield, and appearance of the final product and then identify the steps in which costly inputs could be reduced. We also should find ways of reducing the escalating cost for disposing of effluents from processing lines. Data from computer models and pilot food-processing lines should be applicable to all early steps in processing that are similar for commercial production of canned, dehydrated, or frozen foods.

We must find new uses for commodities that are underused—or even wasted. Of the 20 billion pounds of agricultural fats and oils produced annually in the United States, 8 billion pounds is unsuitable for food. Despite excesses, we still import certain oils for lubricants, soaps, and detergents and for other specific uses. Inedible fats now are converted to food-grade fatty acids by costly, energy-intensive methods. Enzymatic processing could feasibly enhance the utility of underused agricultural fats and oils. Chemical modification of soybean oil might enable the production of extreme-pressure lubricants—formerly based on sperm oil. We must expand efforts to convert our abundance of agricultural fats and oils into substitutes for petroleum and other imports.

The starch that our crops produce in such abundance has many direct uses. It has been modified chemically into many products, such as "super slurper" for unequaled absorbency and xanthate for removing heavy metals from waste water. Renewable, natural starch polymers can be used in biodegradable plastics, and other derivatives have potential uses in processing rubber and in manufacturing urethane foams. Through basic studies of the chemistry of starch, one of our least expensive agricultural products, we should be able to develop new products with high value and utility.

We could increase the utility or export of many products by finding ways to decrease their cost or to improve their quality and acceptance. Improved methods for tanning hides could help restore the competitive position of the U.S. leather industry and reduce our trade deficit of $2.5 billion for imports of shoes. We should reduce the losses and improve the acceptability of the frozen variety meats that we export (valued at $300 million in 1980). Exports of U.S. citrus fruits are increasing, but we need ways for overcoming foreign restrictions that limit our exports of citrus or other horticultural crops. Scientists must continue to help solve emergency problems—such as the infestation by the Mediterranean fruit fly in California—that affect the marketing of commodities. The most important U.S. exports are grains and oilseeds, and we must develop the new methods needed for inexpensive, rapid sampling and grading so that we can maintain and increase their value and acceptability. The ARS must pursue, with renewed vigor, research that facilitates the profitable marketing of U.S. agricultural products.

## Objective 5
## Develop the Means for Promoting Optimum Human Health and Well-Being Through Improved Nutrition and Family Resource Management

Nutrition is a key factor in the degree to which we achieve the genetic potentials inherited from our forebears. The potentials include those for growth, reproduction, resistence to disease, longevity, and intellectual development. The great array of foods now available contributes to our unprecedented opportunity to reach those potentials during longer and more productive lives. However, our knowledge of the relationship between our nutrition and the degree to which we achieve our potentials is inadequate. The signs and symptoms of most of the severe nutritional deficiencies are known, but the thresholds of deficiencies that cause mild adverse effects are ill defined. Our inability to specify optimum nutrient intakes for people who are at those ill-defined thresholds of deficiency is a major challenge to research.

Methods for detecting and measuring abnormalities of physiological functions are insensitive and, consequently, the range of function that is considered "normal" has been very wide. New and improved technologies should enable us to refine procedures and techniques for measuring function. Also, our enhanced appreciation that "normal" in the statistical sense does not necessarily mean optimum physiological function for individuals should stimulate our efforts to develop ways for defining "normal" in a physiological sense for each person. We need improved methods for determining whether marginally or mildly deficient diets impair function and for measuring the degree of impairment. Such methods will help us to understand the relationship between nutrient intake and ultimate expressions of our genetic potentials. Future nutrition research, therefore, should be strongly oriented toward defining the effects of mild deficiencies or excesses of nutrients on physiological function and on physical and mental well-being over the whole life span.

Research on humans must be conducted under carefully controlled conditions so that any sensitive measurements of function that are developed can be applied in a reproducible manner and interpreted properly to discover the relationships between specific nutrients and physiological functions. Those relationships could be studied in groups of people whose suboptimum physiological functions might be related to their nutritional status. Information from such studies could provide the basis for identifying population groups that would benefit the most from programs for nutrition education and intervention. To minimize risk and cost, we routinely study the complexities of nutrition in laboratory animals. However, in the final analysis, findings must be verified in human subjects, and people worldwide could be the ultimate beneficiaries.

**Approach 5.1**

**Define the Nutrient Requirements of Humans at all Stages of the Life Cycle.**

**Approach Elements**

**5.1.1** *Establish the nutrient requirements of infants, children, and adolescents.*

**5.1.2** *Establish the nutrient requirements of pregnant and lactating women.*

**5.1.3** *Establish the nutrient requirements of adult humans.*

**5.1.4** *Establish the relationship between nutrition and aging.*

Together, the two categories "pregnant or lactating women" and "infants, children, and adolescents" account for about 30 percent of our Americn population. Common to all individuals in those categories is their need for nutrients to meet the specific demands of growth and development. Nutrients for the fetus, the infant at the breast, the child, and the adolescent must provide for a metabolism that is geared to support the rapid growth of the brain, muscles, bones, and all other tissues and to store energy. Failure to meet those nutritional needs during the periods of rapid growth and development could limit, for a lifetime, both the level of genetic potential reached and the ultimate quality of life. We need research programs that will help us ensure that those nutritional needs are met.

Among middle-aged people, obesity is the most widespread nutritional disorder and may adversely affect the health of 30 percent of the men and 40 percent of the women. People become obese when either their energy intake is too high or their output is too low. With present techniques, however, we cannot determine which factor, or what combination of the two, causes obesity in any given individual. We must discover the dietary factors that affect appetite and explore the consequences of satisfying energy needs with different proportions of the major dietary sources of energy. Through the use of stable-isotope techniques, we must study the metabolism of cabohydrate, fat, and protein in human subjects. The human body contains at least 40 minerals, many of which are essential for function. Only by understanding the biochemical reactions that depend on those minerals as cofactors can we establish optimum intakes. We should define, more specifically, the minimum requirements for known vitamins and determine the effects of megadoses of certain vitamins.

The average American now can expect to live to 73 years of age and, by the year 2000, should expect to live well past 80 years. The significance of nutrition in the aging process can be considered in relation to three observations. First, the efficiency of many physiological functions declines progressively throughout adult life, and nutrition may influence the rate of decline. Second, the etiologies of some chronic diseases and disabilities that are associated with aging are influenced by nutritional factors. Finally, food intake generally diminishes with advancing age, but we have little solid knowledge as a basis for recommending optimum intakes of individual nutrients by older people. We need research programs that address the specific nutritional requirements of the elderly for maintaining their functions.

**Approach 5.2**

**Determine the Nutrient Content of Agricultural Commodities and Processed Foods as Eaten, and Establish the Bioavailability of Their Nutrients.**

**Approach Elements**

**5.2.1** *Compile essential data on the nutrient contents of foods as consumed in the United States.*

**5.2.2** *Determine bioavailability of nutrients in foods as consumed.*

The establishment of policies and the development of plans for national and international food and nutrition programs require accurate knowledge of nutrient content of food. Since the classic USDA Bulletin No. 28, "The Chemical Composition of American Food Materials," was published in 1896, the Department has published and repeatedly updated a series of food-composition tables. Research organizations, public-health professionals, nutritionists, dietitians, and individuals worldwide rely on the data compiled in USDA Handbook No. 8, "Composition of Foods: Raw, Processed, Prepared." The Human Nutrition Information Service will continue to compile and refine those data. However, to study in certain groups of people the elusive relationship between specific nutrients and physiological function, ARS scientists must chemically analyze the nutrients in the foods that actually are eaten by those people. For such studies, accuracy of the data is critical for trace elements, ultratrace elements, and other nutrients that could be essential in minute amounts, but toxic in larger amounts. Chemical determinations of those nutrients require skilled analysts and are time consuming and costly. To acquire accurate data for the entire diet eaten by individual subjects in the groups studied, we must develop improved methods of sampling and new, automated, and cost-effective methods of analysis.

To understand the role of U.S. agriculture in human health, we should be able to predict the effects that the practices used in all phases of producing, processing, and marketing foods have on the nutritional quality of our diets. The use of fertilizers is an example of practices that can affect the composition of foods. We must study the relationships between the nutrient quality of the samples that are assayed and the history of the foods.

By chemically analyzing samples, we can measure the total amounts of nutrients in a food, but we cannot measure the portion of the total that would be absorbed and used by either laboratory animals or humans. That portion, which indicates the bioavailability of nutrients, can be measured only by bioassays. In our studies of the relationship between diet and the physiological function of people, we must consider the bioavailability, as well as the amounts, of nutrients that foods provide. To determine the bioavailability of specific nutrients in foods, we must develop improved, cost-effective methods for their bioassay. Some nutrients interact with other nutrients, and with some nonnutrients, to alter bioavailability.

Evidence indicates that mineral elements with similar chemical characteristics often compete with one another in plant and animal systems. Zinc and copper interact, and, at marginal levels of nutrient intake, one metal can affect adversely the absorption and metabolism of the other. Interactions of this type are not limited to mineral elements. Absorption of iron is improved by the presence of an animal protein factor or ascorbic acid, or both, and—conversely—absorption of dietary iron, zinc, and calcium can be impaired by phytate and by some components of dietary fiber. People who eat excessive amounts of protein may experience loss of calcium and a weakening of their bones, but some evidence suggests that increased intake of phosphorus prevents calcium losses. We must study specific interactions and assess their importance in human nutrition.

**Approach 5.3**

**Improve the Nutritional Status of Humans and the Well-Being of Families by Making Techniques Available for Assessing the Effectiveness of Nutrition and Home Economics Programs.**

**Approach Elements**

**5.3.1** *Provide means for improving understanding of dietary practices, food-consumption patterns, and their determinants through assessments.*

**5.3.2** *Develop reliable, efficient, and inexpensive methods for defining nutritional status and evaluating nutrition action programs.*

**5.3.3** *Develop methods for improving family economic stability and security.*

We now recognize the need for more sophisticated and accurate methods for assessing the nutritional status of our population. In food-consumption surveys, data usually are collected by the dietary-recall system, which is expensive and prone to errors. The ARS must develop rapid, inexpensive methods for collecting food-consumption data that will accurately reflect dietary habits. In the United States, patterns of dietary practices and habits vary widely among geographic areas, demographic groups, and economic levels. We need more information to understand those patterns and their relation to human health. We must be able to assess and monitor the nutritional status of known high-risk groups—including infants, pregnant and lactating women, the elderly, and the poor. We must also be able to identify other groups of people that could be at high nutritional risk and to monitor changes in their nutritional status.

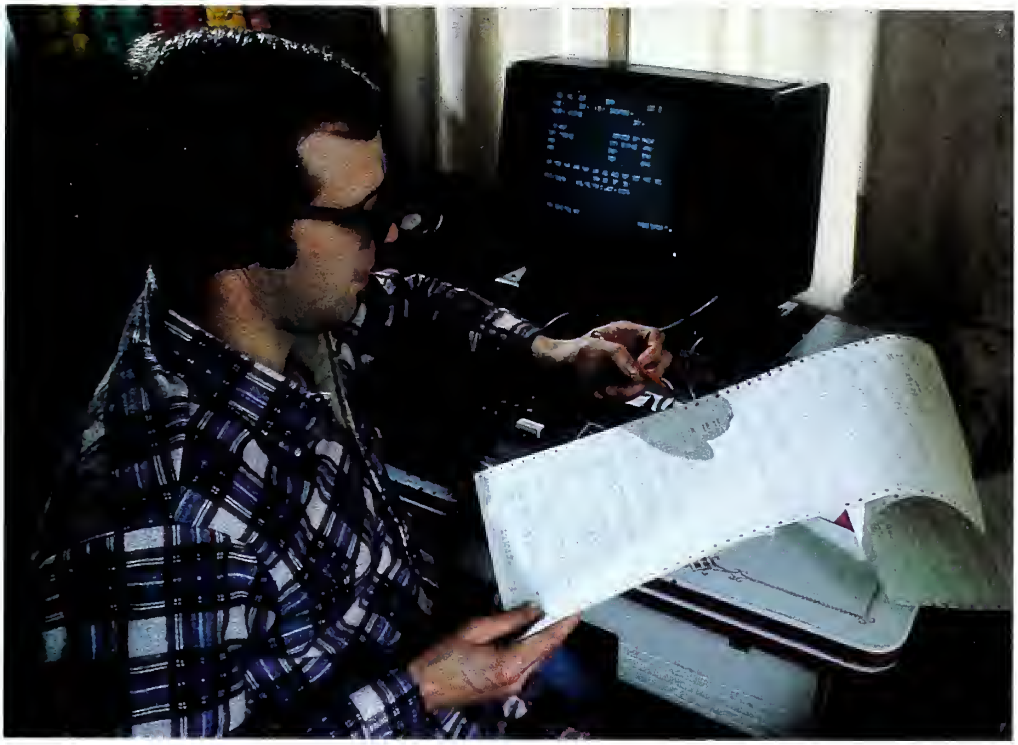
With efficient methods of data collection, scientists should be able to (1) determine what foods people in all groups actually eat and how their eating habits affect their health (2) identify the factors that influence their eating habits; and (3) determine the influence of USDA policies and of programs for nutrition education and intervention on the health, nutritional status, and performance of our citizens.

We know that people with marginal deficiencies in some nutrients suffer altered behavior and impaired performance. Nutrition-related epidemiological research on the many social, environmental, behavioral, economic, cultural, and physiological factors that influence nutritional status will influence the design and evaluation of nutrition action programs. To help ensure the success of such programs, as well as to improve the nutritional status of all our citizens, we must continue our search for biochemical indicators that could be used as simple, specific, and sensitive indexes for evaluating nutritional health. Such indexes also could provide an early warning of potential food and nutrition problems that require remedial action.

As the world's leading producer of food, our agricultural enterprise influences the health of both our citizens and the citizens of the countries that import our farm products. Through its research, ARS will clarify our understanding of the relationship between food and human health and develop improved methods for measuring the true nutritional value of foods for humans. Despite the high cost and complex protocols involved, we must ultimately test our research findings in studies of human subjects. Only the findings from such studies would justify drastic changes of either our procedures for the production, processing, and marketing of foods or our dietary habits. Changes in some of those factors, however, could improve our nutrition and help us increase the degree to which we achieve our genetic potentials.

An integral factor in good nutritional status is effective management of family resources to provide for an adequate amount of nutritious food for all members of the family unit. Some income groups spend the major portion of their wages for food and clothing. However, the food they buy may not meet their nutritional needs. We must find means by which we can help families to manage their resources in a way that will ensure the adequacy of their nutrition and, at the same time, help them achieve economic stability and security.

**Objective 6**
**Develop the Means for Integrating Scientific Knowledge of Agricultural Production, Processing, and Marketing Into Systems That Optimize Resource Management and Facilitate Transfer of Technology to Users**



Agriculture must be much more sophisticated in the next century than it is now. We will no longer be able to afford the losses of soil, profligate use of energy and water, and waste of good food that we now tolerate routinely; we must develop systems that conserve those resources. We must integrate data from the basic and applied research—described above in objectives 1 through 5—into models that simulate agricultural activities and practices. Then—by the process of systems analysis—we can compare efficiency among the simulated activities and select those with the most promise for testing and validation in actual experiments. Systems analysis should help increase efficiency in production and marketing, improve assessments of environmental consequences, and foster technology transfer.

Agricultural production must be viewed as a continuum in which financial, human, and natural resources are used for producing, processing, and marketing food and fiber for domestic consumption and export. No part of the continuum can be viewed in isolation because each part affects the other parts. The nutritive value of food and feed and the quality of fiber and other products depend upon the soils, fertilizers, and germplasm used to grow them and the marketing and transportation practices used to handle and deliver them. The costs of agricultural products and the profitability of each phase of agriculture ultimately depend upon the efficiency with which the products are grown and delivered to consumers. As consumers, we are tied fast to farmers and processors, and vice versa. All of us are tied to our resource bases—soil, water, air, germplasm, and energy. Modeling and systems analysis can help us to make this continuum more understandable and manageable and, in many instances, to prevent unwanted side effects.

Many examples, such as improved cropping systems, illustrate the potential power of systems analysis for improving agricultural technology. Traditionally, growers have selected individual technologies "cafeteria style" from those available and tried to use them in their own operations. Modern technologies, however, are becoming so complex and costly that evaluating them by trial and error is no longer practical. To predict which of the available technologies offer the greatest promise of success, we must test them by simulation modeling. For simulations of complex technologies, we must use advanced methods of computing and handling data to incorporate the findings of different scientific disciplines into submodels.

To find the optimum combinations of crops, fertilizers, water management, and pest control for about 10,000 different soils and for the array of diverse climates across the United States, we must integrate the submodels of technologies into models of agricultural systems. To prove which technologies and systems offer the greatest promise for success, we must test the predictions from the models in practical, multivariate field experiments.

Systems analysis also could help to dispel the commonly held notion that high productivity can be attained only at the expense of resource conservation. Because of our great wealth of natural resources, we have not always tried to achieve conservation and productivity simultaneously. The best defense against soil erosion is provided by dense, productive stands of plants that produce ample crop residues. High-yielding crops use about the same amount of water as low-yielding ones, and water-use efficiency is highest when all other growth factors are optimized. The same is true for energy-use efficiency. The challenge, then, is to find ways to reach high and stable levels of crop production with minimum exploitation of limited and expensive resources.

Improvement of the Nation's rangelands offers another opportunity for the use of models. We cannot conduct experiments on all of the more than 30 major rangeland ecosystems in the United States; we can systematically identify needs and make improvements only through the use of models. Models now being developed to quantitatively describe the characteristics of rangelands will simulate the complex functional relationships among soils, water, vegetation, livestock, and climate. Model inputs should include the latest research findings on weed and brush control, water management, reseeding, new grasses, and improved livestock. The natural biota and recreational and scenic values also must be considered. Then, so the results of the simulations will be reliable and useful to ranchers and land managers, we must validate the models by testing their predictions in appropriately located and designed experimental ranges.

We need integrated research in which basic scientific and engineering principles and concepts are applied to the grower-processor-distributor continuum. The location of processing facilities adjacent to production centers and the use of computerized marketing and delivery systems should improve efficiency. Effective coordination among the components of the continuum should prevent excessive losses, maintain the quality of food, and reduce energy consumption.

We need models especially for the development of alternative farming systems. Many people, most of them employed off the farm, use common agricultural practices to farm small acreages. Their operations may be too small for the technologies and marketing systems used by commercial farmers. Many of those people have neither the time to keep up with the latest research findings nor the money to adopt them. Many other people, who may farm either small or large acreages, want to avoid the use of agrichemicals and to maximize the potential for using crop rotations and for recycling animal wastes and crop residues. People in both groups need information that will enable them to make the best long-term use of their resources and to maximize their profits. Many of the same kinds of problems are characteristic of agriculture in the tropical and subtropical zones of the world, and systems analysis can also help solve those problems.

Because modern agriculture is energy-intensive, and energy costs are an increasing burden in all phases of production and marketing, we must conduct research on ways to reduce the dependence of agriculture on fossil fuels. We will include research designed specifically for conserving energy in production, processing, and other phases of agriculture; finding alternative sources of energy, such as biomass, and converting those sources to useful products; substituting wind, solar, and other noncritical sources of energy for fossil fuels; and ameliorating the effects of energy development.

We have sufficient experience with modeling to know that it is effective. The ARS has developed several models—including the Universal Soil Loss Equation (USLE); Modified Universal Soil Loss Equation (MUSLE); Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS); and Simulation of Cotton (SIMCOT)—that simulate major components of agricultural systems. Other organizations have developed economic and management models for agricultural systems that will be useful to ARS. Conversely, agencies such as the Economic Research Service will be able to use those physical and biological models for production forecasts and for economic and policy analyses. The USLE is used worldwide for predicting the effects of management practices on soil erosion. The CREAMS model recently was adopted by the Soil Conservation Service for predicting the effects of different farming practices on water quality.

The ARS and its cooperators have started to integrate submodels into models of large systems. The EPIC (Erosion Productivity Impact Calculator) model, which predicts monthly soil erosion for specific soils by various crop, rotation, and tillage practices, has the following six submodels: (1) soil, water, and nutrient budgets; (2) weather simulation; (3) biomass-crop-growth simulation; (4) tillage- and residue-management simulation; (5) soil erosion; and (6) production-cost budgets. Submodel 6 provides the information—on cost, income, and risk—that farmers need when they adopt conservation practices. The EPIC model should also be useful to many agencies in guiding policy decisions and action programs for crop production and resource conservation; several have expressed interest in using the model. The SPUR (Simulation of Production and Utilization of Rangelands) model is being designed to predict range productivity, evaluate the effects of various management practices, help transfer research results to users, and identify further research needs. It has submodels for climate, hydrology, plants, animals, and insects. Possibilities for technology transfer linkages with economic models and use of remotely sensed data are under investigation for SPUR.

**Approach 6.1**

## Develop Integrated Systems for Efficiently Producing, Processing, and Marketing Agricultural Products.

**Approach Elements**

**6.1.1** *Assess and quantify the critical interactions among the different factors needed for producing and marketing food and agricultural products.*

**6.1.2** *Develop predictive models for simulating the effects of key physical and biological factors on agricultural productivity and environmental quality.*

**6.1.3** *Establish and operate multivariate experiments on integrated agricultural systems to validate models, facilitate technology transfer, and serve as a base for agricultural productivity forecasts.*

**6.1.4** *Develop technology for using remotely sensed data to assess and maintain the conditions of our natural resources and to provide information for resource models.*

Problems are typically solved in disciplinary research through the collection of data for individual components—such as soils, plants, insects, and livestock—of a system. Those physical and biological data must be assembled into models of individual systems that can account for the interactions among components. Computer models must accurately and realistically simulate agricultural systems. Their accuracy and validity must be established in appropriate pilot tests and field experiments before the findings can be transferred to users.

The modeling approach has several advantages. First, it is efficient. Time frames of many years can be simulated quickly and inexpensively for many locations and management strategies. Second, an unlimited number of management strategies can be considered, whereas in field experiments only a few can be considered. Third, modeling is a research tool that provides knowledge about agricultural processes and identifies the research that is needed to fill gaps in knowledge. The development of models that simulate specific components of the agricultural system is described in other objectives of the ARS Program Plan. The intent of this objective is to integrate those models of components into models that can simulate even large agricultural systems. Multidisciplinary teams of scientists and engineers will be needed to plan and carry out the modeling and to validate the results.

The ARS has 147 field stations—including instrumented watersheds, range and field research centers, and scientific and engineering laboratories. Cooperating organizations have similar facilities. Many of those stations take measurements and collect data that are useful in the development of submodels and integrated models of systems. "The Census of Agriculture," "Agricultural Statistics," and other references provide information on agricultural production that is useful for developing and testing models. In most instances, multivariate field experiments in various climatic zones or physiographic areas will be required to validate the models. In those experiments, as many as possible of the parameters represented in the models must be individually controlled so that the simulation models will be tested under a wide range of actual conditions. Only then can the results be used with confidence.

An emerging technology—remote sensing—holds great potential for agriculture. Some possible applications include assessing the status of the Nation's resources, estimating the severity of droughts and freezes and their effects on crop yields, scheduling the applications of irrigation water and agricultural chemicals, and forecasting the national or even world production of key agricultural commodities. Many types of sensors may be used, depending upon the kinds of information needed. Types may range from hand-held cameras and radiometers to instruments mounted in airplanes or on satellites. Remote sensing has several potential advantages over conventional technologies, particularly for quickly and inexpensively assessing the condition of crops and soils over large areas.

Data from integrated models, pilot tests, and multivariate field experiments have many practical uses. They can be transferred to potential users, who then can see the actual experimental results and decide which new technologies they want to adopt. Changes in natural-resource bases can be predicted accurately, and steps can be taken to prevent undesirable changes. The field experiments and models will provide a scientific basis for assessing the potential effects, on agriculture, of changes in climate or of increases in carbon dioxide from burning fossil fuels. Similarly, potential adverse side effects of new agricultural technologies can be identified and ways found to mitigate them. Analysis of integrated systems should help to improve the accuracy and timeliness of the Department's forecasts of domestic and foreign production and, in turn, help to reduce speculation and to stabilize commodity markets.

**Approach 6.2**

**Develop Alternative Agricultural Systems, Including Those of Small Scale, That are Less Dependent Upon Nonrenewable Resources and That Are Productive, Efficient, and Sustainable in the Long Term.**

**Approach Elements**

**6.2.1** *Develop the means for small-scale commercial farmers and other small-scale producers to maximize efficiency and productivity.*

**6.2.2** *Develop productive biological/organic agricultural systems that avoid or minimize the use of nonrenewable inputs, conserve soil and water resources, maintain or increase soil productivity, and produce high-quality products.*

**6.2.3** *Develop the knowledge needed for increasing the productivity of tropical/subtropical agricultural systems.*

**6.2.4** *Develop systems and technology for reducing the dependence of agriculture on fossil fuels.*

Within the American agricultural community, two groups of producers have some needs that are recognized but are not met through current research programs. Those groups are popularly referred to as "small farmers" and "organic farmers." The inadequacies of those labels notwithstanding, the methods used by the two groups to produce crops and livestock often differ from those used by most large-scale, conventional farmers. Nearly 20 percent of our total food supply comes from the approximately 2 million farms with gross sales of $40,000 or less, and the number of small farms is increasing.

Systems that include the latest technologies for producing, harvesting, processing, storing, and marketing agricultural products could help to reduce costs, ensure conservation of resources, and provide safe and efficient handling of the food produced by that important segment of agriculture. Research on biological nitrogen fixation, biocontrol of weeds and insects, development of better legume varieties, and effects of organic matter on the growth and survival of soil-borne plant pathogens can contribute to systems for organic or low-energy-use farming.

We may be able to develop agricultural production and marketing systems that are applicable to the small-acreage farmer who uses either biological or chemical methods, or a combination of those methods. We should address the needs of the biologically oriented farmer, whether large or small in terms of acreage farmed. The production systems developed should be characterized by less costly methods and by technologies that are safe, sustainable, and environmentally sound. Essential components of the effort should include innovative research to (1) reduce farm production costs while maintaining a high level of sustainable productivity through the development of efficient and diversified crop- and animal-production systems, (2) ensure the conservation of our natural resources, (3) provide safe and economical ways to move agricultural products from the field to the table, and (4) maintain the value and quality of food.

Two other elements of special importance—elements that typically involve a combination of the research efforts described in objectives 1 through 5—are the development of improved farming and marketing systems for tropical and subtropical regions of the world and the development of technologies for reducing the dependence of agriculture on fossil fuels. The ARS must lend its expertise and research capabilities to developing countries, especially those in the tropical and subtropical regions, to help them become self-sufficient. Research in those countries must address the major aspects of agriculture—conservation of resources, improved productivity of crops and livestock, efficient marketing, and improved nutrition of the people.

The ARS also has the capability to help the agricultural industry to conserve fossil energy and, in some instances, to produce alternative energy sources or petrochemical substitutes. Agriculture has the potential for using wind, solar, and other energy sources for activities such as pumping irrigation water, drying grain, and heating farm buildings. Those potentials must be assessed both for conserving energy and for reducing production costs. The waste from one process or activity may be the fuel or feedstock needed for another process or activity, and systems analysis will help identify such opportunities. Biomass, unlike fossil fuels, is renewable, and many scientists think that recent advances in biotechnology hold promise for the use of biomass as a feedstock for industrial processes that yield such products as rubber, resins, terpenes, proteins, waxes, lignin, a variety of carbohydrates, and many others. The production of crops for biomass, chemical feedstocks, and other industrial uses potentially could help farmers to diversify their operations. Through such diversification of U.S. agriculture, farmers would have alternative markets, and the Nation would have domestic supplies of strategic materials for industry.

## Implementation Strategy—Policies

Strategic planning is a continuous process of making decisions that are based on the best information available, organizing people and resources to carry out those decisions, and evaluating results against expectations. The Program Strategy describes the kinds of research identified by ARS scientists as necessary to meet the short- and long-term needs of agriculture and presents the minimum number of research approaches needed to meet the goal and objectives of the ARS Program Plan. The research approaches are based on current scientific knowledge and will change as knowledge advances or as the research needs of agriculture change.

The purpose of the Implementation Strategy is to provide guidelines for implementing those portions of the Program Strategy that ARS selects as most likely to succeed in achieving the objectives. As shown in figure 4, the ARS Implementation Strategy includes policies, a Six-Year Implementation Plan, and resource allocations. This section contains the statements of ARS policies for the following key activities:

- National planning and coordination,
- Determination of program content,
- Establishment of priorities,
- Program implementation and management,
- Review and evaluation, and
- International activities.

These policies will guide the development of the ARS Six-Year Implementation Plan and the resource projections now being prepared, as well as the development of operational plans for specific programs. The USDA agencies develop budgets on a 3-year cycle; the Implementation Strategy will encompass two budget cycles. The Administrator of ARS will manage the Agency in accordance with the Six-Year Implementation Plan to mobilize the physical, financial, and human resources of ARS that are necessary for addressing the high-priority needs of agriculture and its beneficiaries.

The policies are statements that establish the principles and standards by which organizational objectives will be realized. Policies must be developed for an organization's key functions, responsibilities, and activities. They also must be understood and followed by all members of the organization so that the efforts to achieve the organization's goals will be cohesive. Policies guide decisions and form a basis for collaboration and teamwork in planning and decisionmaking. The following policies provide a stable framework for maintaining the continuity and flexibility needed to foster scientific excellence and high productivity in the ARS research effort.

**Policy 1**
**National Planning and Coordination**

## The Administrator Will Operate ARS as a Managed Activity Coordinated by Plan

The Program Strategy describes the research needed to respond to the formidable challenges facing U.S. agriculture. The ARS, the principal intramural research agency in USDA, is—in turn—challenged to focus its scientific resources on the timely solution of the problems it addresses. The ARS Administrator will ensure that needed plans are developed, updated periodically, and implemented to deploy the physical and human resources of ARS to that end. Such plans will provide a framework and sound foundation for:

- Assigning responsibilities for program and administration within the agency;
- Coordinating research across ARS programs, regions, and areas to ensure effective teamwork and to minimize duplication;
- Coordinating ARS research programs with progress of other research performers, such as the State Agricultural Experiment Stations and industry, to ensure that efforts are efficient and complementary;
- Meeting the research needs of those who use agricultural research, including other Federal agencies;
- Setting priorities for allocating and redirecting resources and developing budget requests to promote scientific excellence and to use the talents of the Agency most efficiently;
- Ensuring that effort is productive and balanced among the 6 objectives and 24 research approaches of the ARS Program Plan, as defined in this document;
- Ensuring that problems are addressed by the most appropriate means in terms of key scientific disciplines, teamwork, and technical approach;
- Ensuring that physical and financial resources are available and used effectively;
- Reviewing and evaluating progress toward the achievement of the objectives; and
- Enhancing the opportunity for ARS scientists to innovatively apply their expertise to critical regional, national, and international problems.

The Six-Year Implementation Plan will be the key document in the overall ARS Program Plan. The development and maintenance of the Six-Year Plan are responsibilities of the Deputy Administrator of ARS and the National Program Staff (NPS). Working with line managers, the NPS—in accordance with that Plan—will assess the full spectrum of scientific needs of the Agency, assess the resources that are available for reassignment, and identify program areas that lack resources. Based on the results of

that work, the NPS will develop options and provide, to the Deputy Administrator, recommendations for resource allocations. The Administrator will then select the research programs for implementation by line managers. He will also select from the options those for which the NPS and the ARS Budget Division will develop budget proposals for submission to the Department. Each year, the NPS will adjust the Six-Year Plan based on budgetary decisions and national priorities. Line managers are responsible for updating their operational plans, in accordance with those decisions and priorities, and for implementing their plans. The ARS scientists are responsible for keeping staff members and line managers abreast of the latest scientific advances and opportunities for progress and for ensuring the scientific excellence of their programs. A coordinated ARS effort will ensure that public resources are expended on scientifically excellent and innovative efforts directed toward high-priority problems.

**Policy 2**
**Determination of Program Content**

**The ARS Research Program Will Include the Full Range of Activities Needed To Achieve the Six Objectives of the Program Strategy**

For steady progress toward achieving the six objectives of the Program Strategy, ARS will balance its efforts between basic and applied research. Basic research produces fundamental knowledge that is an essential scientific resource. In their applied research, ARS scientists will draw on that resource to meet the immediate needs of USDA action agencies, other Federal agencies, and users of ARS research findings. By maintaining the balance between basic and applied research, ARS will competently address the critical problems presented in the 6 objectives and 24 research approaches. Basic research programs will be targeted on problem areas in which inadequate fundamental knowledge limits progress. Other programs will exploit existing knowledge bases and breakthrough areas that have a high probability of significant practical payoff. The ARS programs will emphasize long-term, high-risk research that other organizations probably would not attempt. Interdisciplinary research teams will be formed, reorganized, and redirected as needed to ensure that effort is efficiently focused and that the research leads that promise the widest spectrum of benefits are pursued.

The ARS will concentrate on problems of regional, national, and international scope and importance. Problems of more limited scope, such as adapting research findings to local needs and practices, are generally addressed by the State Agricultural Experiment Stations or other research performers unless particular ARS expertise is needed. The ARS will not conduct research that can be conducted better or on a more timely basis by industry. Cooperative research by ARS and State and industrial scientists will be encouraged as an efficient means for increasing the overall benefits that accrue from public investments in agricultural research.

**Policy 3**
**Establishment of Priorities**

## The Deputy Administrator is Responsible for Establishing Priorities in the Six-Year Implementation Plan and the Derived Budgets. The Administrator Ensures That the Priorities Are Consistent With the Goals of the Department

The priorities established formed the basis for determining program content, for operational planning, and for resource allocations in ARS in three major ways. Priorities will be the foundation for updating the Six-Year Implementation Plan and for planning annual allocations and budget requests. Priorities will guide the allocation of resources in the regions and areas and among competing operational needs. An evaluation of progress in and the plans of each research unit will form the basis for allocations. Research leaders and individual scientists will consider the Agency's priorities in determining which lines of research to pursue within the overall mission of their laboratories and in conformance with the Six-Year Implementation Plan.

Priority setting is complex and dynamic. It is an interactive process among staff and line scientists and includes considerations of both the scientific community and research users. Decisions by the Secretary of Agriculture, Office of Management and Budget, and the Congress will determine the ARS appropriation and can affect the allocation of funds to specific locations and areas of research. Within ARS, individual scientists, along with area and center directors and regional administrators and their staffs, will significantly influence priorities based on their analyses of needs for equipment, facilities, and personnel for exploiting scientific opportunities. Outside of ARS, the Joint Council on Food and Agricultural Sciences and its regional subcommittees, the Users Advisory Board, leaders of farm organizations, industrial groups, and professional societies will influence priorities. The USDA action and regulatory agencies that depend upon ARS for research—agencies such as the Animal and Plant Health Inspection Service, Soil Conservation Service, Food and Nutrition Service, Food Safety and Inspection Service, Agricultural Marketing Service, and Foreign Agricultural Service—will also influence priorities. At times, the research needs of agencies such as the Environmental Protection Agency, Agency for International Development, Department of Defense, National Aeronautics and Space Administration, Extension Service, Forest Service, and Bureau of Land Management will enter the process. Analyses and projections by the Economic Research Service and other agencies also will be considered.

For the setting of priorities, the Administrator will rely on the Deputy Administrator and the NPS to plan, articulate, and evaluate national ARS programs. The NPS identifies research opportunities, research that is conducted by other organizations, and research needs that are expressed by user and advisory groups. The NPS develops recommendations for program redirections and budget requests. Those recommendations will be included in action memoranda, option papers, budget analyses, summaries of program reviews and evaluations, or other appropriate documents. As the direct recipient of the information described above, the Deputy Administrator will establish and articulate ARS priorities. The NPS will update the Six-Year Implementation Plan and, with the ARS Budget Division, develop budgets for that Plan.

The main criteria for setting priorities and allocating resources will be:

- Consistency with the objectives and goals of the Congress, the Department, and the Agency;

- Need for the research as expressed by ARS scientists, user groups, Federal agencies, and the general scientific community;

- Potential benefits expected from achieving the stated objectives;

- Research capabilities and capacity of the scientists, laboratory, or program;

- Probability of success;

- Cost of conducting the research; and

- Amount and kind of research effort conducted by other research organizations.

Several factors may constrain the allocation of resources and kinds of research that ARS conducts and limit the flexibility in resource use. The following factors, which include major constraints, must be considered:

- Availability of scientific expertise. Successful research depends upon the training and experience of individual scientists and upon the teamwork that evolves within and among laboratories. For both individuals and groups, many years are required to reach peak productivity. To help ensure the availability of scientific expertise, the ARS Office of Higher Education will provide guidance on postgraduate and other training opportunities for ARS scientists and others.

- Limitations of geography, climate, and soil. For valid results, certain types of research, especially field research, must be conducted at problem sites and over extended periods.

- Nature of the problem. Much ARS research requires costly facilities and equipment that are problem-specific. Quarantine facilities and special equipment for work on recombinant DNA and foreign animal diseases are examples.

- Sequential nature of research. Often, one phase of research must be completed before the next phase can be started.

- Continuous adaptation of biological systems. Examples are the resistance of crop pests to chemical controls and the genetic improvement of crops that may introduce new vulnerabilities. Goals and priorities must be revised to meet new problems as they arise.

No totally objective formula is possible for setting priorities and allocating resources for research. Priority setting for research is the exercise of informed judgment. It is based on the criteria and constraints listed above; all the factors are important at some level of decision making. At the project level, scientific criteria and experience will predominate. At the national level, scientific criteria must be balanced with Federal policies and with the needs of action agencies and other users of research. It is the task of the Administrator, Deputy Administrator, and the NPS to achieve such a balance so that ARS may provide its scientists with the long-term stability and the firm commitments that are needed for creative research.

**Policy 4**
**Program Implementation and Management**

**The Regional Administrators are Responsible for the Development and Implementation of Operational Plans for Achieving the Objectives of ARS. The Administrator Is Responsible for Overall Coordination and Execution of the Program**

The ARS operates by means of coordinated line and staff activities and responsibilities. Regional Administrators are responsible for field operations managed by four regional offices and staffs, by area directors, and by directors of major research centers. The Deputy Administrator of ARS, located at Headquarters, is responsible for the management and operation of the NPS. The ARS management cadre is responsible for research programs carried out at approximately 150 worldwide locations by 7,600 full-time and 1,000 part-time ARS employees.

The NPS is responsible for developing and providing overall leadership for national research programs in accord with policies 1 and 3. The regional administrators are responsible for operations and operational planning within their respective regions. The staffs for regional program planning and review, the area and center directors, and scientists prepare operational plans in consultation with and subject to review by the NPS. The regional administrators, working with the area and center directors, are responsible for the direct supervision and management of approved research programs and projects. Management support services provide for personnel and for procurement, fiscal, and other functions. Regional administrators are responsible for allocating the resources needed to implement ARS program elements within their regions. They manage the Research Grade Evaluation and Merit Pay Systems by which individual scientists and support personnel are evaluated and rewarded, including the recognition of interdisciplinary research and teamwork.

Line managers play a key role in coordinating research in ARS with that in the Agricultural Experiment Stations, Cooperative Extension Service, Soil Conservation Service, and other agricultural groups of State and regional scope. Through close working relationships with the directors of State Agricultural Experiment Stations, joint research projects, cooperative agreements, and extramural projects are developed as needed to ensure efficient use of ARS personnel and resources.

Line and staff personnel will work together to maintain the integrity and scientific excellence of national programs while efficiently and effectively using ARS resources. The NPS will consult with the regions in developing the ARS priorities and the Six-Year Implementation Plan; the regions will consult and review with the NPS to ensure that the operational plans are consistent with the research objectives and with the priorities of the Six-Year Plan.

**Policy 5**
**Review and Evaluation**

**The Deputy Administrator Is Responsible for the Systematic Evaluation of Programs and of Progress Toward Achievement of the Six-Year Implementation Plan**

The review and evaluation of research programs at many levels in the Agency serve to identify areas of significant progress, major constraints to further progress, emerging research problems and opportunities, and research that can be discontinued. That information will be used in setting priorities, planning and implementing redirections, developing budgets, and revising the Six-Year Implementation Plan and the operational plans.

The NPS is responsible for reviewing national programs and for evaluating their progress and consistency with the Six-Year Plan. To successfully carry out that responsibility, members of the NPS will be recognized experts in their fields and will be expected to maintain their knowledge of the latest scientific aspects of their assigned areas of responsibility. The NPS members will also need broad experience and understanding of interdisciplinary research to recognize and exploit opportunities in related fields or to function as coordinators of problem-solving interdisciplinary teams. They will be prepared to provide authoritative advice as required. Thus, the NPS members serve the Agency as guardians of the continuing relevance and correctness of the technical directions of the ARS program.

The NPS, the Regional Program Planning and Review Staff, and the area and center directors will have operational responsibility for reviewing and evaluating specific programs and units. To spare staff resources, program evaluators will consider the largest practical aggregation of research units. In addition to the appropriate staff and line managers, review and evaluation teams can include top ARS scientists or national technical advisers; representatives from cooperating State Agricultural Experiment Stations, action agencies, and farm and industrial organizations, or other knowledgeable people who can contribute. The review and evaluation teams will develop a formal list of findings and recommendations for implementation by line managers, the scientists, or members of the NPS. (See Directive 600.6.) The regional administrators will then document, and forward to the Deputy Administrator, the plans for and the actions taken to implement the recommendations of the review and evaluation teams.

Area and center directors will review, annually, each research unit and laboratory under their supervision to assess progress on the operational plans and to ensure conformance with the Six-Year Implementation Plan. Although technical matters may be considered, the main purpose of those reviews will be to evaluate operational capability and performance. The adequacy of available physical, financial, and human resources should be assessed, based on the technical objectives to be achieved. Special attention will be given

to identifying opportunities for enhancing technical and leadership capabilities. Findings from and recommendations that result from those reviews will be formally communicated to the Deputy Administrator and to the Regional Program Planning and Review Staff offices.

Scientific and technical excellence demands a continuing review and evaluation of progress by the scientists performing the work. Scientific decisions at the experimental level are best made by those scientists.

Appropriate management information systems will be developed and maintained to meet the specific needs of the Administrator and of the deputy and regional administrators.

**Policy 6**
**International Activities**

**The ARS Conducts Research and Participates in Technology Exchange in Foreign Countries To Complement and Strengthen Domestic Research Programs, To Support International Trade and Development, and To Carry Out Activities Authorized by the Agriculture and Food Act of 1981**

The Administrator of ARS has operating responsibility for international activities. The Assistant to the Administrator for International Activities is responsible for allocation of human and financial resources to foreign activities. The Deputy Administrator and the NPS are responsible for planning, setting priorities, and evaluating international research activities that are an extension of the domestic programs described in the Six-Year Implementation Plan.

As specified in the Agriculture and Food Act of 1981 (Public Law 97-98), ARS also will support U.S. and foreign initiatives that directly benefit U.S. agriculture and provide a substantial contribution to world agriculture. The ARS will work directly with other USDA agencies, such as the Foreign Agricultural Service, Office of International Cooperation and Development, and Animal and Plant Health Inspection Service; other Government agencies, such as the Agency for International Development, Departments of Defense and Commerce, National Science Foundation, and State universities; and international institutions, such as the Food and Agriculture Organization, World Bank, International Atomic Energy Agency, and World Health Organization to produce the greatest benefits from research and technical-exchange programs.

# Appendix

## The Planning Process

The Agricultural Research Service Program Plan has several purposes. It presents the goal and long-term objectives of the Agency. Those objectives address the current and future needs of agriculture for managing its natural resources, producing and marketing food and other products, and providing nutritious and wholesome foods at reasonable costs. The Plan describes the kinds of research that scientists of the Agricultural Research Service (ARS) think will be needed to achieve the objectives. The intent is to communicate, in an understandable way, the relevance and importance of the agricultural sciences for the future well-being of the United States. The Plan describes the way in which ARS plans to mobilize its scientific resources to help achieve the objectives with a balanced strategy of basic and applied research. The Plan also provides for the continuous review, evaluation, and updating of ARS research to ensure both scientific excellence and continued relevance.

In the first step in the planning process, the goal and six objectives were established. Then, members of the National Program Staff (NPS) drafted a set of 67 proposed courses of action, or research approaches, for achieving the objectives. Each approach was assigned to a selected ARS scientist for further development. Those 67 scientists, who represented many of the 150 ARS locations, then—in turn—enlisted the help of many other scientists to ensure full consideration of commodities, disciplines, and problem areas. More than 500 scientists contributed to the effort. During a period of about 3 months, the scientists developed written materials that defined the scope and scientific content of the approaches. A coordinator for each objective assisted in organizing the written materials. Because of the high cost of holding meetings and workshops, most participants used an electronic mail system to permit maximum interaction and to speed communications.

The scientists concentrated on science and research strategies and avoided defending or projecting current operating programs and organizational structures. Those issues would be addressed later in plans for operations and programs. Scientists organized each research approach into one or more approach elements, which—in turn—contained one or more project areas. A project area was defined as a significant block of scientific work (3 to 10 scientists working with support for 1 year) needed to implement the approaches. The scientists provided the following information for each approach element and project area:

- The nature of the problem to be solved and its scientific and agricultural importance;

- State-of-the-art or current research status and critical research needs or events for further progress;

- The kinds of results expected (reports, vaccines, germplasm, models, etc.) and length of time needed to produce those results;

- Potential benefits and impacts that can be expected if the research is successful;

- Probability of successful achievement; and

- Relative priority of the research.

That information was used to help develop and define the final set of research approaches, approach elements, and project areas. Duplication was eliminated, and only the approaches that were essential to achieve the objectives were selected. Objective coordinators and members of the NPS then developed brief narrative summaries for the final research approaches and approach elements.

The final 24 research approaches that were selected from the 67 originally proposed describe research areas that offer important opportunities for increasing the productivity of agriculture. Examples of those opportunities are improving germplasm resources, reducing losses of crops and livestock, increasing the effectiveness of the marketing sector, and conserving soil and water resources. The research areas described are of lasting importance to agriculture, other agencies, and the public and have high potential for continued progress. A catalog of project areas has been prepared for use in resource projections, but it will not be published. Members of the NPS are now developing the resource projections needed for use in the Six-Year Implementation Plan, which, in turn, will guide the preparation of operational plans by line managers. The Six-Year Implementation Plan and the operational plans will be revised, as appropriate, to reflect the latest scientific findings and most urgent needs of agriculture.

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